Marine Animal Forests
A Manifesto

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Key Messages

Marine Animal Forests (MAFs) are among the most widespread yet understudied ecosystems; their decline poses risks to global marine biodiversity, food supplies, and carbon cycles.

1. Definition of Animal Forests:

- Marine benthic ecosystems dominated by sessile animals such as corals, sponges, and bivalves that form three-dimensional structures analogous to terrestrial forests.

- Provide habitat complexity, shelter, and are often biodiversity hotspots.

2. Global Distribution:

- Found from tropics to polar latitudes, shallow intertidal zones to deep-sea environments (e.g., cold-water coral reefs, Antarctic sponge grounds).

3. Ecosystem Engineers:

- Modify habitats by enhancing structural complexity, stabilizing substrates, and influencing hydrodynamics and nutrient cycling.

4. Biodiversity and Function:

- Support high species diversity; diversity of tropical reefs rivals that of rainforests.

- Provide ecosystem services: Coastal protection, fisheries support, clearing water, and carbon sequestration and immobilization.

5. Threats from Human Activities:

- Bottom trawling, overfishing, and coral harvesting degrade MAFs habitats (e.g., Mediterranean red coral populations reduced to "grasslands").

- Climate change (bleaching, ocean acidification) and pollution exacerbate declines.

6. Carbon Immobilization:

- Animal forests immobilize carbon, storing it in their tissues and calcium carbonate skeletons, and distribute excess carbon (in photosynthesized MAFs) to fish and invertebrate inhabitants.

7. Reproductive and Resilience Challenges:

- Slow growth and long lifespans (e.g., black corals live >4,000 years) often hinder recovery from disturbances.

- Connectivity between populations (larval dispersal, genetic diversity) is critical for resilience but threatened by habitat fragmentation.

8. Knowledge Gaps:

- Limited data on deep-sea and subpolar animal forests (e.g., African/South American coasts).

- Need for studies on reproduction, metabolic pathways, and species-specific responses to stressors.

9. Conservation and Management:

- Urgent need for marine protected areas (MPAs) and bans on destructive practices (e.g., bottom trawling).

- Interdisciplinary approaches (ecology, socioeconomics) essential for sustainable management.

10. Scientific Outreach:

- Public awareness is low compared to terrestrial forests; the "animal forest" concept bridges this gap by leveraging familiarity with terrestrial ecosystems.

What are Marine Animal Forests and why are they important?

Marine Animals Forests are three-dimensional ecosystems created by animals living physically attached to or embedded in the sea floor that provide new ecological niches and additional surfaces for other animals to colonize, resulting in increased biodiversity and an increase in ecological function and ecosystem services[1]. In the current biodiversity crisis, conserving hotspots of biodiversity and areas providing enhanced ecosystem services is paramount, as these areas play an enhanced role in sustaining life on our planet.

Why are scientists concerned about Marine Animal Forests?

Marine Animal Forests are impacted by many of the anthropogenic pressures identified in the Marine Strategy Framework Directive[2].

For example, anchoring, recreational diving, and fishing with bottom contact gears can cause **physical disturbance to the seabed** destroying the physical integrity of the Marine Animal Forests. Fishing, be it commercial, artisanal, or illegal, causes **extraction of, or mortality/injury to, wild species** that form or inhabit Marine Animal Forests. Port works and coastal infrastructure development can lead to **physical loss** of habitat and **changes to hydrological conditions** which may be particularly detrimental to the filter feeders that often dominate Marine Animal Forests. Sewage and other run-offs and discharges cause **input of nutrients, input of organic matter, input of litter**, and **input of other pollutants**, all of which are particularly detrimental to ecosystems formed from sessile animals. Climate change is **causing input of forms of energy** which may be detrimental, and cumulative when combined with other pressures. Examples include temperature increases through global warming, and increased waviness and storminess that can impact shallow sessile ecosystems.

Many Marine Animal Forests in European waters are either not protected or are inadequately protected[3].

Historical destruction of Marine Animal Forests

We have definitively lost the red coral forests of octocorals shaped like small vermilion trees that once thrived on the Mediterranean seafloor. This is perhaps one of the least known, yet most tragic, losses in our seas.

Precious corals have been traded since antiquity, with red coral (*Corallium rubrum*) exploitation dating back to the Paleolithic period. Ancient engravings depict free divers harvesting large branches of red coral from shallow waters, suggesting it was once abundant at accessible depths[7].

Over time, extraction expanded and industrialized as shallow-water coral stocks dwindled. Depletion forced divers to venture deeper, employing more men and boats in pursuit of the prized "red gold." This practice resembled mining more than fishing—locating a coral bank, stripping it bare, and moving on to the next. One of the most spectacular sources of *C. rubrum* was discovered in Sardinia's legendary Capo Caccia Cavern at 37 meters. Reports from 1956 describe divers working at 30–35 meters, but by 1958, they had already descended to 40–45 meters. By 1964, teams were risking depths beyond 70 meters, fueling a deadly "coral fever" that led to numerous accidents among young divers.

Red coral vanished entirely from some regions, never to recover. In others, towering "trees" (once 20–30 cm tall, with branches up to 50 cm and trunks over 3 cm thick) were reduced to stunted blades, barely 4–8 cm high and a few millimeters at the base. Millennia ago, the Mediterranean's rocky coasts must have been adorned with vast red forests—a living stone paradise built by these slow-growing organisms. As an eco-engineering species, their three-dimensional structures added immense complexity to the marine ecosystem. Now, the vermilion forests are gone, and substantial restoration efforts are required if we are to witness their splendor again[7].

Ongoing degradation of Marine Animal Forests

Blue mussels are key ecosystem engineers, forming biogenic reefs, often supporting significantly richer and more diverse fish communities than equivalent areas of soft seafloor[4]. Across the globe, mussel reefs continue to degrade. A decadal delay in defining the blue mussel reef habitat, and variations in definitions across EU member states, mean that blue mussel reef remains poorly protected in many European waters, threatening the objectives of Nature 2000 areas, despite the requirement to protect blue mussel reefs as a biogenic reef under the Habitats Directive[5].

Blue mussel reefs become physically degraded through mussel dredging and bottom trawling. Overfishing can have consequences beyond physical impacts. For example, overfishing of Atlantic cod, which are natural predators of shore crabs, has led to elevated numbers of shore crabs in Denmark, which prey heavily on blue mussels. Eutrophication of coastal waters is causing oxygen depletion, also impacting survival of blue mussels.

A multipronged approach to protection and restoration requires dredging and bottom trawling to cease, eutrophication to be tackled at source, and an ecosystem approach to management. Research recommends protecting coastal areas where habitat-forming blue mussels regularly occur rather than trying to protect individual reefs using ambiguous reef definitions. Large-scale restoration of blue mussel reefs could substantially improve the biodiversity of coastal habitats, including supporting the life-cycle of the threatened European eel, which favours the mussel habitat as juveniles in coastal areas[6].

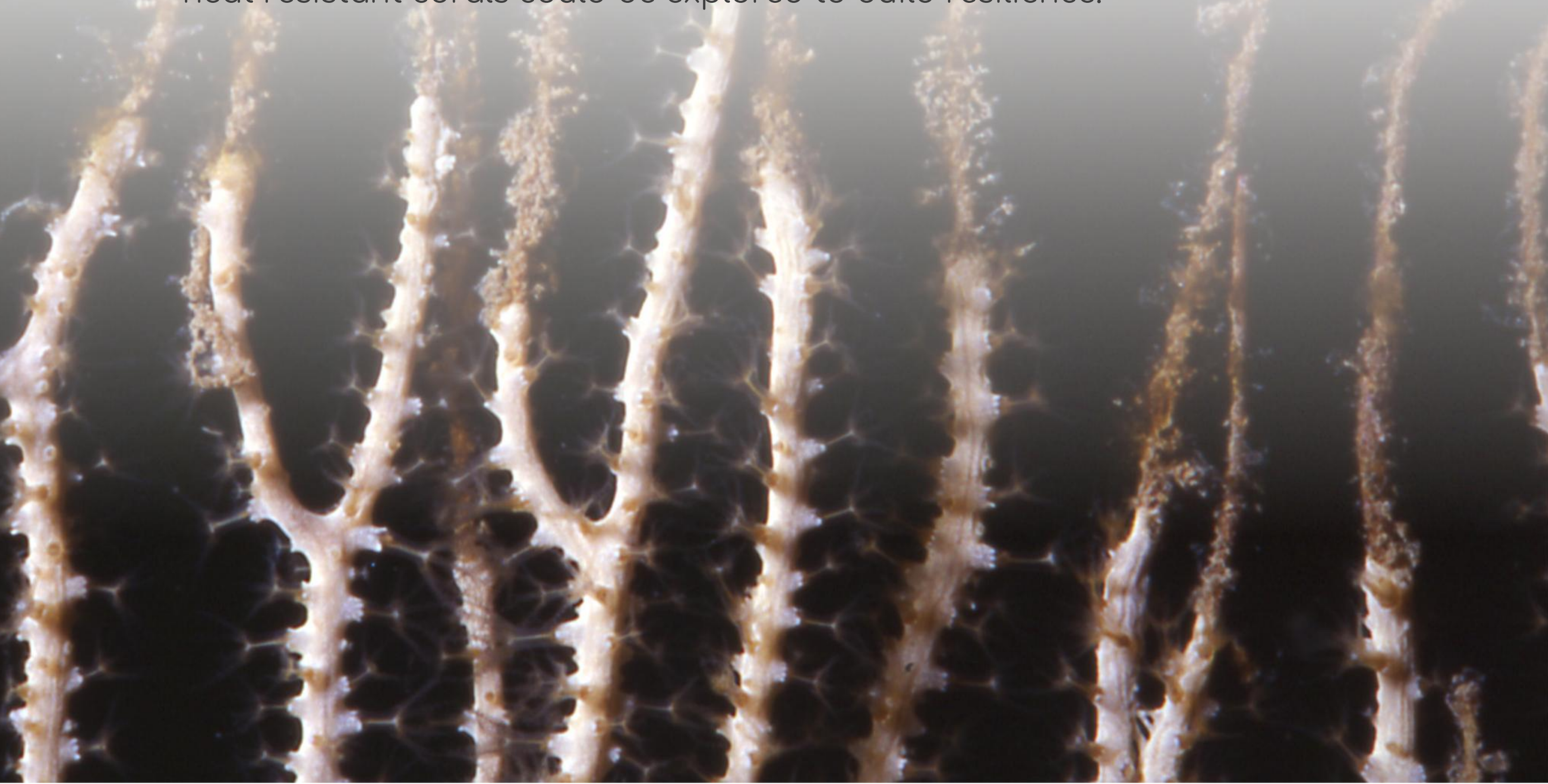
Heatwaves and Marine Animal Forests

Heat waves, driven by climate change, are increasing in frequency and intensity, causing severe stress to marine ecosystems. Two key systems affected by these pressures are tropical coral reefs and the Mediterranean Marine Animal Forests.

In coral reefs, symbiotic algae (Symbiodinaceae) are expelled, leading to loss of color and energy starvation. Warmer waters hinder coral skeleton formation, weakening reef structures, and fish and invertebrate populations decline due to habitat loss. As an example, between 2016 and 2017 back-to-back bleaching events killed 50% of the Great Barrier Reef's shallow-water corals.[8]

In the Mediterranean Sea, heat waves that increase surface waters by as much as 4-5 °C impact the Marine Animal Forests even in water as deep as 50 meters[9]. Species like *Paramuricea clavata* (red gorgonian) suffer necrosis which can cause 80–100% of the population to die. Heat disrupts feeding that relies on delicate filtering mechanisms and makes animals like sponges more vulnerable to disease. The loss of the animals which give three-dimensional structure to the habitat leads to a simpler ecosystem with fewer animals. Even low-light mesophotic habitats occurring at 30–150 metres depth are now affected.

More than ever, Marine Protected Areas and restoration plans[10] can help maintain the functionality of the systems by removing compounding pressures. Initiatives such as assisted evolution or selective breeding of heat resistant corals could be explored to build resilience.



Bottom trawling and the destruction of Marine Animal Forest

Bottom trawling, which involves dragging heavy nets across the seafloor, is one of the most destructive fishing practices. It severely damages slow-growing, fragile marine animal forests—complex ecosystems built by corals, sponges, and gorgonians that provide critical habitat for marine life[11].

Among other things, trawling gear crushes coral frameworks, sponges, and gorgonian colonies, and the sediment resuspension chokes filter-feeding species (e.g., sea fans, glass sponges). 3D structures collapse, displacing fish, crustaceans and other invertebrates, and long-lived species (e.g., *Desmophyllum pertusum* reefs) may take centuries to recover. There is a reduction of carbon immobilization and the sponges and corals that trapped organic carbon instead release it. The loss of fish nursery grounds affects commercial fish stocks[12].

In Mediterranean coralligenous assemblages, bottom trawling can destroy 80-90% of coral in trawled areas. In the Northeast Atlantic, trawling through cold-water coral communities reduced coral cover by 50-80% in some zones. Trawling removed up to 95% of glass sponges from Canadian sponge grounds. Some deep-sea ecosystems may never fully recover, and there is an evident collapse of fisheries dependent on these habitats[13].

Carbon flux and immobilization

Marine Animal Forests act as carbon immobilizers. Carbon immobilization is the process whereby the animals retain, for an extended period, carbon from the water column in their structures[13]. Estimates of carbon amount retained by terrestrial forests, seagrasses, mangroves, crops, and soils are available. There is scarce information on the amount of carbon retained by Marine Animal Forests and their importance as carbon immobilizers needs quantifying. This will likely reveal the importance of their preservation and active restoration, leading to such approaches being better appreciated[14].

As an example, consider an annual cycle of suspension feeding organisms that are seeded on an Integrated Multitrophic Aquaculture (IMTA) facility. Seeding diverse suspension feeders (polychaetes, ascidians, bivalves, sponges, etc.) near fish cages or sewage outflows offers a dual benefit: bioremediation and carbon immobilization. The animals associated with Marine Animal Forests filter water while immobilizing carbon, and their biomass can be dried and repurposed—e.g., for biogas production.

Approximately 15 kg of fresh weight/year of animals can grow on a 15-meter vertical rope. This is equivalent to around 3–4 kg of dry weight or approximately 1 kg of carbon. If this were scaled up, a 100-meter line with 200 ropes could immobilize 200 kg of carbon within 400 m^2 (4 m width × 100 m length). This would yield 0.2 tons of carbon per 400 m^2/year, or 5 tons per hectare/year—a measurable metric for carbon sink calculations.

Biodiversity credits for Marine Animal Forest

A proposed support for conservation and restoration plans is the creation of transparent and verifiable credits. Unlike carbon credits, biodiversity credits are more complex to define and quantify. With no universally accepted unit to describe biodiversity, the challenge is to create a straightforward system for quantifying biodiversity credits.

No single index can fully capture all the elements of biodiversity, especially across different species and habitats. Thus, the approach must integrate multiple indices, including a sessile biodiversity index, a mobile fauna, (including fish and invertebrates) biodiversity index, an associated fauna index, and a functionality index[14].

The rationale behind this multi-index approach is to capture the variety of biodiversity dimensions present in Marine Forests in general, using coral reefs as a case study. Because sessile organisms like corals and sponges contribute to habitat complexity, they support a wide array of species. Mobile fauna play crucial roles in nutrient cycling and energy flow. The associated fauna index considers the small but essential organisms living in close proximity to these habitats, while the functionality index evaluates how well the ecosystem performs in terms of services like carbon storage[15] and nutrient recycling. Together, these indices offer a holistic view of biodiversity, making it possible to create a biodiversity-credit system that reflects the true ecological value of restored marine habitats.

What must we do to protect and restore?

Reduce Pressures	Reduce land-based Pressures (e.g., litter, eutrophication, pollution)
	Reduce sea-based Pressures (e.g., fishing, anchoring)
Engage Stakeholders	Raise awareness
	Early detection through citizen science
	Local site stewardship
Increase Scientific Knowledge	Better habitat mapping including fine-scale mapping
	Science to support Natura 2000 and MPAs in conservation/restoration: genetics, climate refugia modelling
	Better description of individual MAFs
Protect & Restore	Create protected areas
	Active restoration, including with artificial reefs
	Actions on invasives
Better Manage	More surveillance and stricter enforcement of existing legislation
	New legislation e.g., Portugal banned coral from boats without a licence

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