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Workshop Report

Marine Animal Forests of the World: Definition and Characteristics

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Abstract

The term Marine Animal Forest (MAF) was first described by Alfred Russel Wallace in his book “The Malay Archipelago” in 1869. The term was much later re-introduced and various descriptions of MAFs were presented in great detail as part of a book series. The international research and conservation communities have advocated for the future protection of MAFs and their integration into spatial plans and, in response, there are plans to include the characteristics of MAFs into national policies and international directives and conventions (i.e. IUCN, CBD, OSPAR, HELCOM, Barcelona Convention, European directives, ABJN policies etc.). Some MAF ecosystems are already included in international and national conservation and management initiatives, for instance, shallow water coral reefs (ICRI, ICRAN) or cold-water coral reefs and gardens and sponge aggregations (classified as Vulnerable Marine Ecosystems, VMEs), but not as a group together with

other ecosystems with similar ecological roles. Marine Animal Forests can be found in all oceans, from shallow to deep waters. They are composed of megabenthic communities dominated by sessile suspension feeders (such as sponges, corals and bivalves) capable of producing three-dimensional frameworks with structural complexity that provide refuge for other species.

MAFs are diverse and often harbour highly endemic communities. Marine animal forests face direct anthropogenic threats and they are not protected in many regions, particularly in deep-sea environments. Even though MAFs have been already described in detail, there are still fundamental knowledge gaps regarding their geographical distribution and functioning. A workshop was dedicated to clarifying the definition of MAFs, characterising their structure and functioning, including delineating the ecosystem services that they provide and the threats upon them. The workshop was organised by Working Group 2 of the EU-COST Action “MAF-WORLD” (hereafter WG2), which is responsible for collating and promoting research on mapping, biogeography and biodiversity of MAFs, to identify and reduce these knowledge gaps. Herein, we report on this workshop and its outputs.

Keywords

Marine Animal Forest, structural role, functionality, ecosystem services, threats, conservation, policy

Contributors

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Date and place

The workshop was held online on 10 March 2022.

List of participants

In total, 41 participants from 19 different countries with diverse professional backgrounds and affiliations participated in the workshop. Dr. Nur Arafeh Dalmau, an external expert with experience in the policy-science interface, also attended the Workshop, while Prof. David Johson (GOBI, Seascape consultant) and Dr. Ellen Kenchington (DFO, Canada), both of whom have extensive expertise in science and policy, provided comments on the workshop’s results. The majority of the participants were from European countries, but there were also participants from Brazil, Japan, Thailand, Australia, Taiwan and South Africa (Table 1) (Fig. 1).

Table 1.

List of participants (in alphabetical order) in the workshop, including affiliation and country.

	Participant name	Affiliation	Country
1	Ricardo Aguilar	OCEANA	Spain
2	Louise Allcock	NUI Galway	Ireland
3	Suchana Apple Chavanich	Chulalongkorn University	Thailand
4	Nur Arafeh Dalmau	University of Queensland	Australia
5	Genuario Belmonte	University of Salento	Italy
6	Meri Bilan	University of Salento	Italy
7	Simona T. Boschetti	Joint Research Center - EC consultant	Italy
8	Lorenzo Bramanti	Observatoire Oceanologique Banyuls sur Mer	France
9	Marina Carreiro Silva	University of the Azores	Portugal
10	Carlo Cerrano	Universita Politecnica delle Marche	Italy
11	Giovanni Chimienti	Department of Biology, University of Bari	Italy
12	Federica Costantini	University of Bologna	Italy
13	Thanos Dailianis	Hellenic Centre for Marine Research	Greece
14	Vianney Denis	National Taiwan University	Taiwan
15	Julian Evans	University of Malta	Malta
16	Charlotte Havermans	Alfred-Wegener-Institute	Germany
17	Paulo Horta	Universidade Federal de Santa Catarina	Brazil
18	Kerry Howell	University of Plymouth	UK
19	Georgios Kazanidis	University of Edinburgh	UK
20	Darina Koubínová	University of Neuchâtel	Switzerland
21	Piotr Kuklinski	Institute of Oceanology, Polish Academy of Sciences	Poland
22	Vesna Mačić	University of Montenegro	Montenegro
23	Francesco Mastrototaro	University of Bari	Italy
24	Christian Mohn	Aarhus University	Denmark
25	Monica Montefalcone	University of Genoa	Italy
26	Declan Morrissey	NUI Galway	Ireland
27	Covadonga Orejas	IEO-CSIC	Spain
28	Marco Palma	Universita Politecnica delle Marche	Italy
29	Alexa Parimbelli	NUI Galway	Ireland
30	Slavica Petović	University of Montenegro	Montenegro

	Participant name	Affiliation	Country
31	Massimo Ponti	University of Bologna	Italy
32	Maria Rakka	University of the Azores	Portugal
33	James Reimer	University of the Ryukyus	Japan
34	Buki Rinkevich	National Institute of Oceanography	Israel
35	Sergio Rossi	University of Salento	Italy
36	Maria Salomidi	Hellenic Centre for Marine Research	Greece
37	Toufiek Samaai	University of the Western Cape	South Africa
38	Maria Sini	University of the Aegean	Greece
39	Eva Turicchia	University of Bologna	Italy
40	Şükran Yalçin Özdilek	Canakkale Onsekiz Mart University	Turkey

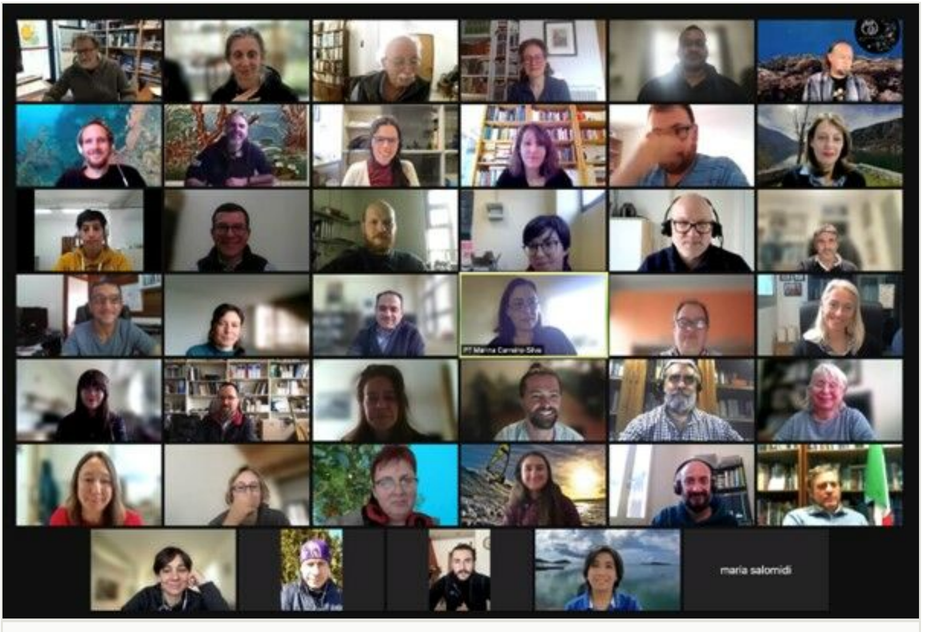

Figure 1. doi

Screenshot from one of the Workshop plenary sessions (source: screenshot of the workshop zoom).

Background

Marine Animal Forests (MAF) is a term used to describe some of the world's most biologically important (i.e. extremely diverse, productive and distinctive) yet frequently under-studied marine benthic habitats. Marine Animal Forests are benthic ecosystems dominated by megabenthic invertebrates (> 1 cm), mostly suspension feeders, that form three-dimensional frameworks of different sizes and sometimes canopies[*1] with great structural complexity that serve as habitat, refuge, food supply and nursery for other species. We use the term "animal forest" for communities dominated by anthozoans, sponges, bryozoans, sea pens, ascidians, tube worms or hydrozoans, amongst others.

In their structural role and partially in their functionality, these communities resemble the structure of terrestrial forests (Fig. 2, but the main habitat-forming species are animals rather than plants. The term Marine Animal Forest is not new: In 1869, Alfred Russel Wallace (Wallace 1869) wrote in his book "*The Malay Archipelago*" the following: "*The depth varied from about twenty to fifty feet, and the bottom was very uneven, rocks and chasms and little hills and valleys, offering a variety of stations for the growth of these animal forests*". He was referring to suspension feeders, such as corals and sponges, dominating the reefs. Marine Animal Forests, like terrestrial forests, can be dominated by a single species (e.g. monospecific mussel beds or sea pen assemblages, forming populations) or by multiple species with varying morphologies and functionality (e.g. some sponge beds, cold-water coral reefs and gardens, tropical and subtropical shallow water coral reefs, hydrozoan meadows, mussel beds, forming communities).

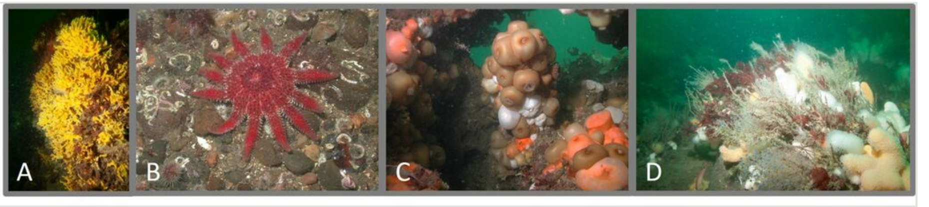

Figure 2. doi

Some examples of Marine Animal Forests in Danish waters: (A) Community of *Porifera* with scattered red algae in the area of the Great Belt bridge, (B) Common seastar (*Crossaster papposus*) with assemblages of sea urchins (*Strongylus centrotus*) and polychetae (*Pomacoteros triqueter*) at Schultz's Grund in the Southeast Kattegat, (C) Reef structure made by bubbling methane of Frederikshavn in Kattegat dominated by the sea anemone *Metridium senile*, (D) Community of soft corals, hydrocoans and the red algae *Phycodrys rubens* (Kattegat, 'Chinese Wall', 18 m depth). Images were kindly provided by Karsten Dahl (Aarhus University; Copyright Karsten Dahl with permission to publish under the terms of the Creative Commons Attribution 4.0 License).

Due to their high vulnerability to anthropogenic impacts, some MAFs, such as shallow water coral reefs and deep-sea habitats like cold-water coral reefs and gardens and sponge aggregations, are already included in conservation and management initiatives. Shallow coral reefs have been particularly impacted by anthropogenic impacts due to their proximity to shore and human population dependency on the resources they provide. They are also one of the most species diverse marine ecosystems and as such protected under several international initiatives (e.g. International Coral Reef Initiative (ICRI) and International Coral Reef Action Network (ICRAN)). Deep-sea species have particular life history characteristics, such as long-lived, slow growth and low reproductive output that hampers their recovery from human disturbance. Concerns raised on the impacts of fishing activities (specially bottom trawling) and long recovery times of these animals have resulted in the consideration of the habitats they form (e.g. cold-water coral reefs and gardens, sponge aggregations) as Vulnerable Marine Ecosystems (VMEs) (UNGA Resolution 61/105, FAO 2009) and as priority habitats in need of protection (OSPAR 2010). Further, other anthropogenic activities, such as drilling and mining, are already and will become potentially even larger threats to these communities. However, these initiatives only cover a few emblematic MAFs and/or target specific anthropogenic impacts. Therefore, it becomes important to create a set of unifying criteria that help define habitats that constitute MAFs that can be used for management and conservation purposes. Several less recognised MAFs, such as hydrozoan forests, bryozoan and tube worm reefs, have important, but less appreciated ecological roles in many regions of the world and require more attention from policy-makers for their conservation and management.

As such, one aim of Working Group 2 (WG2: Underwater mapping, biogeography and biodiversity) within the “MAF-WORLD” COST Action is to produce a list of criteria helpful to identify which ecosystems may be defined as MAFs for consideration in national, regional and international management and conservation policies, thus providing a common basis to draw attention to their importance.

Objectives of the Workshop

The workshop's main goal was to bring together marine specialists from around the world and gather information and expertise from them to better define MAFs. We particularly focused on the aims below:

- To identify criteria for defining, recognising and describing potential MAFs (Topic 1 for discussion; see below for details), which will be used to set up common “language” amongst researchers working in tropical, temperate and polar regions, as well as shallow, mesophotic and deep-sea MAFs. The main goal is to generate a unifying technical definition, as well as a set of criteria useful for policy-makers.
- The workshop participants also discussed key structural and functional roles that characterise MAFs (Topic 2 for discussion; see below for details) and their importance as suppliers of ecosystem services (Topic 3 for discussion; see below for details), as well as the threats endangering these ecosystems (Topic 4 for discussion; see below for details). The discussion aimed to contribute to the generation of the definition for MAF, as well as the set of criteria.
- The concepts and criteria developed in the workshop are intended to be used in international, European and national strategies for marine conservation (i.e. CBD’s Global Biodiversity Framework, EU Biodiversity Strategy, EU Habitats Directive, other strategies at national level). Therefore, as the main output of the workshop, a paper including the concept and characterisation of MAFs will be submitted to an international scientific journal.

Workshop scope and logistics

Covadonga Orejas and Marina Carreiro Silva led the online event on 10 March 2022, with Toufiek Samaai, Christian Mohn, James Reimer and Louise Allcock providing assistance. Christian Mohn provided technical support for the workshop, which took place via the Zoom interactive platform. Topics 2, 3 and 4 were run in parallel sessions in separate Zoom breakout rooms (Topic 2: C. Orejas as moderator and T. Samaai as rapporteur; Topic 3: L. Allcock as moderator and M. Carreiro-Silva as rapporteur; Topic 4 Christian Mohn as moderator and James Reimer as rapporteur), with discussions, examples, experiences, terms and criteria delivered using the Zoom interactive platform. A final general discussion and poll completed the workshop.

Agenda

The agenda consisted of a general introduction that provided background to the workshop, followed by discussions about the four major topics in breakout groups. The list of topics, as well as a background document, was shared with all participants before the workshop. The assigned moderators and rapporteurs guided and made notes of all the discussions and these were collated and used to produce the current report. The four topics with key aspects as guidance for discussions are listed below.

Topic 1: Defining criteria "what are MAFs? vs. Ecologically and Biologically Significant Areas (EBSAs) and Vulnerable Marine Ecosystems (VMEs)"

- Avoid duplicating criteria (albeit there are clear synergies), consider that the concepts of EBSAs and VMEs were established in relation to CBD and UN Sustainable Fishing policies, respectively and we, therefore, should consider aspects that distinguish the various concepts.
- Use several criteria that are broad enough to include less iconic species/groups.
- Ensure criteria are practical and beneficial to policy-makers (VME criteria are a good example of how to formulate criteria for MAFs).
- Consider scales (size and temporal).

Topic 2: Structural and functional roles of MAFs

- Topic 2 provides a strong basis for defining the criteria mentioned in Topic 1.
- Examine aspects that are "distinctive": (e.g. the presence of a "canopy", its function in the Blue Carbon budget, bentho-pelagic coupling, biogeochemical cycles and non-permanent animal forests).
- Consider functional roles of organisms and habitat and canopies as a whole.
- What is the importance of MAFs in carbon sequestration and Blue Carbon budgets?
- Consider regional differences in densities, habitat associations and the biodiversity supported by MAFs.
- Compare ecological roles of permanent vs. ephemeral MAFs.

Topic 3: MAFs as suppliers of ecosystem services

- As biodiversity hotspots/fish and invertebrates of commercial interest associated with MAFs.
- In terms of Blue Carbon.
- As climate archives.
- In natural-cultural heritage.

Topic 4: Threats to MAFs

- What are the threats to MAFs?
- What are the effects of these threats to MAFs?
- How can these threats affect the diversity, structure and function of MAFs?
- What are the relevant EU and other policies for protecting MAFs?

Agenda timing

Time (CET)

Activity

10:00 – 10:10 Short introduction, goals.

10:10 – 10:40 Round 1 – Discuss Topic 1 (all participants work in breakout groups).

10:40 – 10:55 Rapporteurs present the major outcomes from discussions in each breakout group.

11:00 – 11:30 Round 2 – Discuss Topics 2, 3 & 4 (all participants work in breakout groups).

11:30 – 12:00 Share reports from each breakout group.

Lunch Break

13:30 – 14:00 Round 2 – Discuss Topics 2, 3 & 4 (all participants work in breakout groups).

14:00 – 15:00 Final discussions Topic 1. Finding consensus on criteria defining MAFs at the end of the workshop via poll and discussion.

15:00 Close of the workshop.

Workshop outcomes

Key outcomes of discussions for Topic 1

The first session considered the descriptions of MAFs included in the book from Rossi et al. (2017b), the benthic invertebrates that form MAFs and their ecological role, as well as comparisons and contrasts amongst MAFs, EBSAs and VMEs.

For the discussions, three potential descriptions of MAFs were considered. Lack of data to quantify the dominant habitat forming species and variation in size and density of dominating species in different MAFs led to a focus on functionality as a defining characteristic. Specific characteristics, such as “unique”, “rare”, “fragile” and “long-lived” were not accepted as applying to all MAFs. Redundancy of terms used in previous descriptions was also discussed: there was a preference for a short, simple and clear definition that would be accessible to policy-makers and non-experts.

When discussing criteria that best define MAFs, workshop participants were generally of the opinion that a description should give particular emphasis to the role of MAFs as ecosystem engineers and to the importance of their three-dimensional structure in providing shelter and functional complexity to other species. The size, geographical extent and depth ranges were not considered as suitable criteria for distinction of MAFs, but it was considered that the MAF description should mention that MAFs may encompass differently-sized organisms and occur over wide depth and geographic ranges.

It was noted that MAFs:

- Are composed of ecosystem engineers.
- Produce three-dimensional structures that provide architectural and functional intricacy, as well as shelter for a variety of animals.
- Alter local sediment conditions (as well as currents), facilitate the life cycle of associated species and promote habitat cascades.
- Are composed of benthic communities mostly dominated by sessile or reduced-motility animals.
- Comprise heterotroph/mixotroph metazoans.
- May be long-lived (i.e. coral reefs, bivalve assemblages) or ephemeral (i.e. some hydroid meadows) communities.

Key outcomes of discussions in breakout sessions Topics 2 – 4

Topic 2

The structural and functional roles of MAFs were discussed in Topic 2. The key elements, including three-dimensional structure, in the make-up of a MAF were discussed, as well as how MAFs may be quantified. We debated whether to include canopy, as defined in terrestrial forests, in the MAF description. It was decided to exclude it from the MAF criteria due to a lack of understanding of the term canopy in terms of animal forest.

In addition, some MAFs do not form a true “canopy” (e.g. sea pens, mussel beds, sponge aggregations), but still substantially increase three-dimensional complexity and have important functional roles as habitat providers or in nutrient and carbon cycling. Participants discussed "what species make a MAF" because it is inevitable that species and habitats must be conserved.

The role of microbes (microbiomes) was discussed, giving consideration to the concept of the holobiont, the assemblage of a host and the many other species living in or around it, which together form a discrete ecological unit. Within this framework, we further discussed ecosystems services including Blue Carbon budgets and carbon sequestration, generation of microclimates, roles in the bentho-pelagic coupling and biogeochemical cycles, as well as the importance of considering any MAF definition also encompassing ephemeral animal forests.

Microbial actions, benthopelagic coupling, biogeochemical cycling and microclimate modifications were considered to be important functions of MAFs. The scientific debate about whether MAFs can be considered Blue Carbon ecosystems similarly to coastal wetlands (seagrasses, salt marshes, mangroves) is still ongoing. Certain MAFs, such as tropical coral reefs, sequester CO_2 in an indirect manner, whereas others do not. In calcifying species, such as mussels and corals, the majority of the carbon is retained in their carbonate skeletons as opposed to being sequestered through organic C and fluxes.

The last topic of discussion was what makes MAFs unique. Based on group discussion, the following are some of the main defining characteristics we consider need to be included when generating a set of criteria:

- Some MAFs are ephemeral (i.e. hydrozoans meadows) and some are not vulnerable.
- MAFs are not always rare, unlike VMEs
- MAFs are composed of secondary producers
- MAFs are composed of mostly sessile animals or with limited mobility (i.e. crinoids)
- The canopy is also important in many MAFs.

Topic 3

We discussed ecosystem services initially under the Common International Classification of Ecosystem Services (CICES) framework. The group identified and discussed different categories of services, including provisioning, regulating, cultural and supporting services. Most of the identified services were associated with well-studied or emblematic MAFs, such as shallow-water coral reefs, oyster reefs and mussel beds. The group recognised the need to identify and describe services and functions of less well-known MAFs (e.g. bryozoans, hydrozoans) in future efforts. The group also discussed the need to better value cultural services provided by MAFs, particularly their aesthetic importance in terms of spiritual value and human well-being. People will better support the need to preserve and protect MAFs if they can spiritually connect with them. Images of MAFs available through educational materials and websites may be very useful tools. We agreed that it is important to determine who benefits from these ecosystem services and who loses when any of these ecosystem services are lost. A list of ecosystem services provided by MAFs was produced.

Provisioning services:

- Food provision - Fish and invertebrates (e.g. mussels, oysters) of commercial interest associated with MAF fisheries and aquaculture
- Provision of sand, construction materials – shallow coral reefs

- Pharmaceutical, biotech and genetic resources
- Habitat provision
- New unaccounted resources that will become important due to future technological developments.

Regulation and maintenance:

- Coastal protection – erosion, storms, currents – shallow coral reefs as breakwaters
- Clean water – e.g. oyster reefs
- Biogeochemical cycling – evidence for sponge grounds (e.g. sponge cycle), coral ecosystems
- Benthopelagic coupling
- Blue Carbon – potential CO_2 sequestration in anthozoan skeletons
- Climate archives – long-lived anthozoans.

Supporting services:

- Biodiversity hotspots
- Resilience of marine ecosystems – diverse marine ecosystems promote more resilient systems
- Nursery grounds - for example, sea pen fields, shallow water coral reef lagoons.

Natural-cultural heritage:

- Tourism (e.g. shallow coral water reefs)
- Educational value
- Aesthetic importance – spiritual value, human well-being.

We discussed the function of MAFs in terms of habitat cascades, recognising that a habitat becomes a MAF when the animals within it are sufficiently dense to function as one. We acknowledged that not all MAFs provide the same ecosystem services. In order to provide clear guidance to policy-makers and conservation organisations, there is a need to identify knowledge gaps and conduct further research to describe the ecosystem services which different MAFs provide. The group identified it as important to describe ecosystem services and their functional role by MAF type, depth (shallow, mesophotic, deep sea) and region. Blue Carbon is a particular area of importance in this regard that need to be explored. Determining which MAFs can be considered carbon sinks and over what time scales should be a priority, although it should be taken into account that there currently is a debate on the potential role of MAFs as carbon sinks.

Finally, we discussed the stable environments (although some are also ephemeral) provided by some MAFs and their importance as providers of new biodiversity across evolutionary time scales.

Topic 4

Possible threats and their effects and impacts on MAFS were discussed in Topic 4. In addition, existing EU and other key policies addressing potential threats were identified.

What are the threats to MAFs?

We gathered a list of a wide variety of threats to MAFs detailed below:

- Climate change. Expected to impact all MAFs, but impacts already noticeable for shallow water MAFs, such as coral reefs as direct effects of increased seawater temperature and reduced pH (acidification) on bleaching and death of coral reefs or mass mortalities of sessile invertebrates and indirectly through increased incidence of pathogens (see below).
- Deep-sea: The main threats are trawling and in general fisheries (i.e. nets, long lines). The generation of sediment plumes from bottom trawling and extraction of oil and gas and associated impacts, such as blanketing of filter-feeding organisms are a serious threat to many deep-sea MAFs. Deep-sea mining is not yet a main threat, but is expected to be soon (i.e. plans for the exploitation of polymetallic nodules (amongst others)); this is an invasive technology with potential for large-scale disruption of MAFs.
- Fisheries can exert a direct pressure on MAFs (i.e. through targeted harvesting of species, such as precious corals) or indirectly (e.g. mechanical damage by fishing gear, bycatch of branching sponges and corals, smothering by ghost nets).
- Natural changes are also possible, such as changing hydrodynamics in the deep sea. It was noted that perhaps this could also be related to effects of climate change.
- For shallow water reefs (e.g. tropical and subtropical shallow water coral reefs and mesophotic coral ecosystems (MCEs)), the main threats to these MAFs are climate change (e.g. marine heatwaves, instability in temperatures) due to global warming, as well as more local-scale issues, such as pollution and oil spills/accidents (e.g. illegal dumping is still an issue in many areas), eutrophication, coastal development and land reclamation and open water aquaculture, over-utilisation/collection of commercial species and negative impacts of artisanal and recreational fisheries. Many of these issues impact not only MAFs, but other flora and fauna and potentially adjacent ecosystems.
- There are many other aspects of climate change that are potential threats to MAFs; for example, sea level rise, acidification.
- Increased incidence of invasive and alien species, for example, Caribbean reef and Atlantic Ocean coral reef MAFs, with invasive lionfish, sun corals and octocorals from the Pacific Ocean. Increases in marine garbage increases rafting possibilities for potentially invasive organisms.
- Increased spread of pathogens, due to both increases in garbage/rafting and invasive species, changes in ocean conditions (i.e. temperature increase, pH decrease) and due to the cumulative effects of multiple stressors lowering the resilience of many MAF species. There are numerous well-documented cases of diseases spreading through and damaging MAFs.
- Over tourism is a serious issue at the local scale, particularly for tropical and subtropical shallow water MAFs, where numbers of tourists may exceed the carrying capacities of locations.

- One possible future threat is the presence of more offshore structures. It is not known what their effect will be and this issue needs to be monitored. There is the potential for both positive (e.g. more habitat and increased connectivity for MAFs) and negative effects (increases in invasive species and pollution, alteration of currents).
- Another potential threat is incorrect or erroneous conservation management efforts (based on insufficient knowledge of the ecosystems, spatial data deficiencies, lack of policies). This issue may be of particular concern at local scales.

What are the effects of these threats to MAFs?

- Lowered or increased biomass, biodiversity, loss of uniqueness, changing community structure and dominance, loss of three-dimensional structure and function, loss/reduction of ecosystem services, loss of resilience, ecological shifts (phase shifts), simplification of trophic nets/interactions and feedbacks (simple or fragmented).
- There are likely differences in how generalist and specialist species are affected. Another effect is changes in temporal stability. For example, millennial MAFs changing to 100-year MAFs. These temporal changes are linked to the time-scales of the disturbances (for example Caribbean coral reefs – changing from Scleractinia-dominated to octocoral-dominated etc.).
- Changes may not always be negative, at least from certain points of view.
- Extinction of species? At the least, local extirpation of MAFs or species is likely. As pathogens and stressors increase, an increase in mass mortality events may also occur. An example of this could be coral bleaching or die-offs due to marine heatwaves (e.g. intertidal-zone communities in western Canada in summer 2021, gorgonian shallow water species in the Mediterranean in 2003). Overall, there will be an increase in susceptibility to pathogens and increased risk of disease.
- The interactions amongst multiple stressors – this can be an important effect and should not be overlooked even if not well understood.

How can these threats affect the diversity, structure and function of MAFs?

- Threats will alter distributions, food availability and structures of MAFs.
- Cold-water ecosystems –physical damage from trawling etc. is devastating, particularly as many benthic species are slow-growing. Climate change can reduce distributions (chemical/physical parameters) – for example, *Lophelia* corals in cold-water ecosystems. As well, there will be negative effects for the associated fauna of impacted species. For example, there are many reports examining how the North Atlantic oscillation changes will affect ecosystems.
- There will be an increasing loss of organisms that mitigate cascading effects (e.g. trophic webs). For example, loss of gorgonians in Mediterranean from heat waves alters recruitment of benthos, causing community changes.
- Whatever the direct effects of these various threats, by acting on habitat-forming species, cascade effects and ecological shifts of vast proportions can occur.

- Taking into account interactions of stressors, we should highlight increased changes of niche suitability and we should consider modelling key populations and species.
- The interactions of local and global stressors can be hypothesised; this should be summarised in a publication with a beautiful figure of some kind.
- Regarding effects of stressors on shallow water coral reefs, there is much literature to pick and choose from, investigating various aspects including cultural, tourism, breakwaters, food + ecosystem services all being reduced or otherwise negatively impacted.
- Range shifts of species due to climate change can alter community structure. Range shifts may be an open question in some systems for some organisms (e.g. coral reefs in shallow waters in Japan and Australia). However, with climate change and global warming, larvae should be able to settle in new places and shift polewards; it is not only movement of mobile species.
- Marine ecosystems may experience trophic cascades. The loss of predators due to overfishing can erode ecosystem resilience. Protection can have a positive effect on ecosystem resilience, the recovery of predators within a trophic web may have important and often positive consequences for an ecosystem.
- There will be effects of the resilience of species and MAF ecosystems. However, there is bias in literature for some ecosystems on this topic, with some more well-studied than others. For example, range shifts of shallow water MAF-building organisms and also their food, as well as range shifts of zooplankton, are quite well documented.
- The issues of benthic-pelagic coupling, sedimentation, turbidity, nutrient cycles and how these will change with stressors, need to be considered.
- Finally, it must be remembered that anthropogenic threats to species in the short term may be positive in the long-term or vice versa. We need to consider winners/ losers and consider the biology of each species. Some species have better adaptive capacity, some will do better under different conditions. R or K strategists can represent losers and winners.
- In general, management of continental run-off is a global need. Continents are the main source of nutrients that increase eutrophication and the main source of pesticides. For example, in Brazil, there have been more than 1300 new agricultural pesticide products introduced in 2 years; many of these have already been banned from the EU.

EU and other key policies

- The EU and surrounding regions have many regulations in place that are relevant to MAFs and VMEs. For example:
  - EU regulation 2016/2336 bans bottom trawling below 800 m.
  - EU regulation 2019/1241 regulates fisheries closures of specific areas due to presence of VMEs.

  - Northeast Atlantic Fisheries Commission (RFMO): Move On rule. Article 9, Recommendation 19:2014 on the Protection of Vulnerable Marine Ecosystems in the NEAFC Regulatory Area.
  - Mediterranean Regulation 1967/2006, exploitation of fishery resources in the Mediterranean Sea.
  - EU Biodiversity Strategy for 2030.
- As well, one set of more general and global regulations are the Convention of Biological Diversity conservation targets, which aim to protect 30% of key habitats by 2030. MAFs are important habitats and need to be a priority target included in the “30 by 30” target. This goal is more orientated towards conservation planning.
- There is much literature documenting declining/threatened species habitats in the NE Atlantic.
- We need to consider how the current COST action can contribute and present results to policy-makers.
- Additionally, it must be noted that restoration almost always focuses on “easy species” and efforts ignore long-living or slow-growing species. This problem seems to be common to almost all MAF restoration projects.
- A general comment: do we have somewhere a separation of long-term threats and their effects (environmental, anthropogenic etc.) and short-term events (sudden changes, catastrophes)? We have not considered sudden, short-term events and the expectation is these will increase in frequency and severity as climate change progresses.
- Within the EU Commission, there is much discussion on these topics, but a lack of data hampers this. This WG and the COST action should provide numbers and data.

Key outcomes of final discussion of the breakout session Topic 1

The last session was devoted to a group participatory discussion, focused on delineating the criteria and description of MAFs. As well, there was discussion on overcoming obstacles and moving forward from this workshop.

The Chair of this session prepared the new description of MAFs, based on the advice and opinions from the morning breakout groups on this topic.

The MAF description, as defined in Rossi (2013), (Rossi et al. 2017b) and Soares et al. (2020), were discussed during the workshop.

1. Megabenthic invertebrates that build three-dimensional (3-D) living structures, often including fragile and long-living species, that support high levels of biodiversity and are found throughout the world’s oceans, at all depths from polar to tropical areas (Rossi 2013, Rossi et al. 2017a).

2. MAFs are biogenic habitats created by megabenthic faunal species acting as autogenic ecosystem engineers that change the environment by creating a complex, 3-D biophysical structure. The high biophysical complexity of MAFs provides new ecological niches and

additional surface area for colonisation by associated biota, resulting in an elevated species diversity compared to adjacent areas with similar seabed geomorphology, but lacking MAFs.

3. Benthic communities characterised mostly, but not exclusively, by suspension and filter feeder animals (e.g. sponges, anthozoans, bivalves, hydrozoans, bryozoans) that build 3-D structures, similar to trees, bushes or meadows in a terrestrial forest/ecosystem (Rossi 2013, Soares et al. 2020).

The MAF workshop resulted in a modified description.

New description of MAF: 3D structure formed by benthic animals acting as autogenic ecosystem engineers which provides new ecological niches and colonisation surfaces for other organisms and results in increased provision of functions and services.

This description of MAFs, while developed 'de novo' during the workshop, encompasses two out of five criteria used to define Vulnerable Marine Ecosystems, namely structural complexity and functional significance (FAO 2009, paragraph 42), but is clearly distinct (Fig. 3). VMEs are a subset of MAFs that are unique, rare, fragile and slow to recover from damage and, thus, are particularly susceptible to damage from fisheries, but all MAFs bring enhanced ecosystem functioning and, thus, are of increasing conservation importance in the Anthropocene.

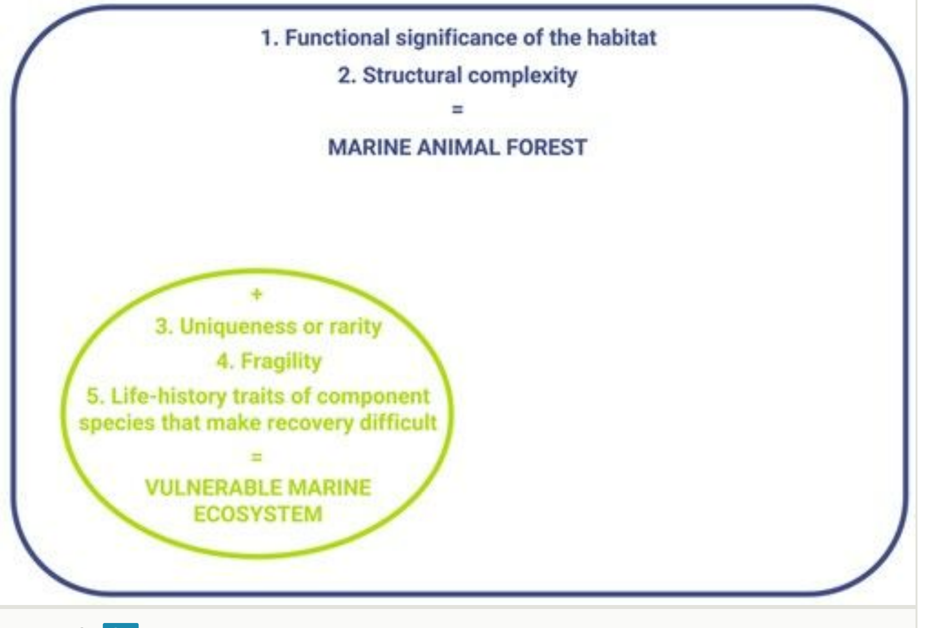

Figure 3. doi

Vulnerable Marine Ecosystems are a subset of Marine Animal Forests. Criteria listed are the five criteria for VMEs given by FAO (2009).

A live poll of all participants determined that 76% (= 26/34) of participants favoured this new definition (Table 2). The Chair then invited those who did not support this definition to articulate their specific criticisms and these were discussed. Minor revisions to the workshop-generated definition, which could include simplifying the language to make it more accessible, should yield a consensus definition that will have wide support in the MAF research community.

Table 2.

Results of the poll to vote for the MAF definition.

Definition	No. of votes
1	4
2	3
3	1
New	26

Conclusions and main outcomes

● We organised and conducted an internationally attended workshop that reached a broad audience with > 40 participants from 19 countries.

● Participants were experts in various fields of MAF biology (i.e. benthic invertebrate ecologists, taxonomists, marine scientists and policy-makers) and this allowed a broad discussion on what MAFs are and are not.

● MAFs have ecological importance and occur from shallow water to the deep oceans and from the polar regions to the tropics.

● We developed a set of criteria and an operational definition of MAFs.

● Participants agreed that it will be important for policy-makers to understand MAFs and their roles in the marine environment.

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Endnotes

*1 The forest canopy is a structurally complex and ecologically important subsystem of the forest. It is defined as “the aggregate of all crowns in a stand of vegetation, which is the combination of all foliage, twigs, fine branches, epiphytes as well as the interstices (air) in a forest” (Parker 1995).