Assessing Marine Litter Impacts on Mesophotic Biogenic Reefs to Guide Restoration Actions in the Northern Mediterranean: The LIFE DREAM Project Approach

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Scope

Reef habitats are among the most biologically diverse yet ecologically fragile marine ecosystems and are highly sensitive to anthropogenic pressures such as the accumulation of marine litter (ML). ML poses a severe, yet often overlooked threat to rocky and biogenic reefs, due to the difficulties in exploring deep or complex underwater environments. Establishing solid scientific evidence on the magnitude of ML impacts on reef habitats is a prerequisite for designing effective mitigation and conservation strategies. LIFE DREAM is an EU-funded project implemented in the northern Mediterranean, aiming to protect and restore reef habitats in alignment with the EU Biodiversity Strategy for 2030 and the forthcoming Nature Restoration Law. Within this framework, the present study assesses the impacts of marine litter on mesophotic biogenic reefs located within the National Marine Park of Alonnissos Northern Sporades (NMPANS), in the Aegean Sea (Greece, Mediterranean Sea) (Fig. 1).

Methods

Five sites within the NMPANS were surveyed in September 2024 (Fig. 1).

Assessments were carried out using the Super Achille Remotely Operated Vehicle (ROV), equipped with a Sony Pan/Tilt/Zoom camera, a GoPro camera with a wide-angle low-light lens (~0.001 lux), and halogen lights (2 × 220 VAC / 250 W and 2 × 12 VDC / 50 W). Two parallel laser beams provided a 10 cm reference scale for metric measurements.

At each site, two transects were conducted: one along the deepest sections of the rocky reefs and a second at approximately 40 m depth, ensuring coverage of reef areas below recreational SCUBA diving limits.

Video footage was manually analysed using standard playback software to characterise benthic habitats and marine litter (ML).

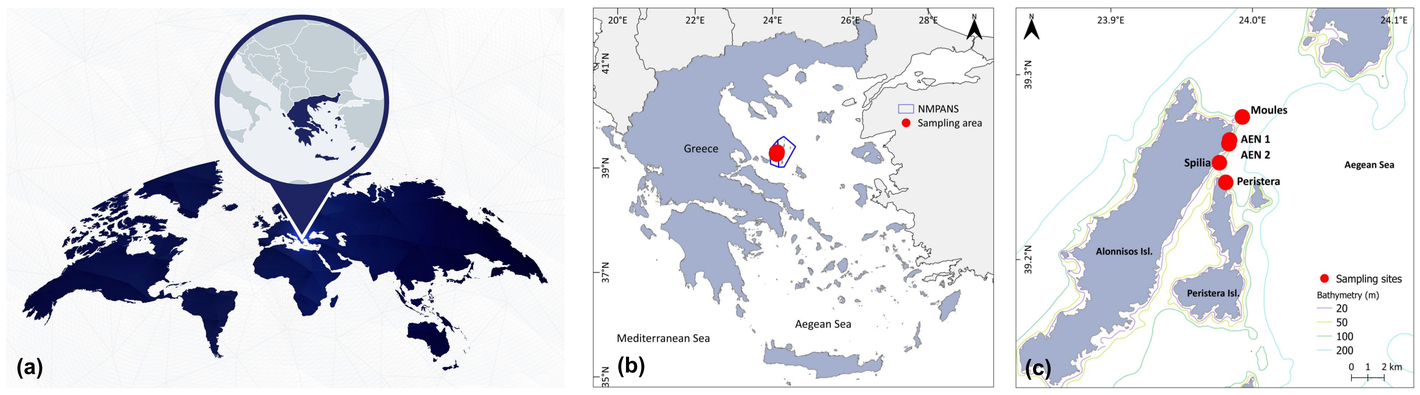

Figure 1: Global map indicating the position of Greece within the Mediterranean (a), the location of the NMPANS and the study area within the Aegean Sea (b), and the position of the five sampling sites (c).

Parameters under study

- Extent of **hard bottom (%)**
- **Basal living cover (%)** as an indirect indicator of biogenic reef: proportion of hard bottom covered by organisms of the basal (encrusting) and intermediate layers (<10 cm in height), including c**oralline algae,** Number (N) of conspicuous megabenthic species
- **Number of structuring and protected species** (N) with signs of epibiosis, necrosis, and entanglement in lost fishing gear.
- **ML type** (following [1]) and **ML abundance** (number of items)
- **ML interaction**[2] with benthic habitats and species: **(a) covering**; **(b) Entangling / abrading** showing visible scars or injuries on substrate or organisms; **(c) Hanging** between obstacles but causing no apparent damage; **(d) Lying** / resting with no tension on the substrate causing no apparent damage.
- **ML biofouling stage**[3] – provides information on residence time, impact potential, and feasibility of removal: **Stage 0** – no biofouling (indicative residence time <1 month); **Stage 1** – presence of few small filamentous algae (1–4 months); **Stage 2** – presence of larger macroalgal and small carbonatic encrusting organisms (4–12 months); and **Stage 3** – well developed communities of multiple conspicuous taxa (>1 year).
- **ML removal feasibility** – based on accessibility, entanglement and biofouling level: (0) **0%** of the item can be removed; (1) **<50%** removable; (2) **≥50<90%** removable; and (3) fully or almost fully removable (**>90%**).

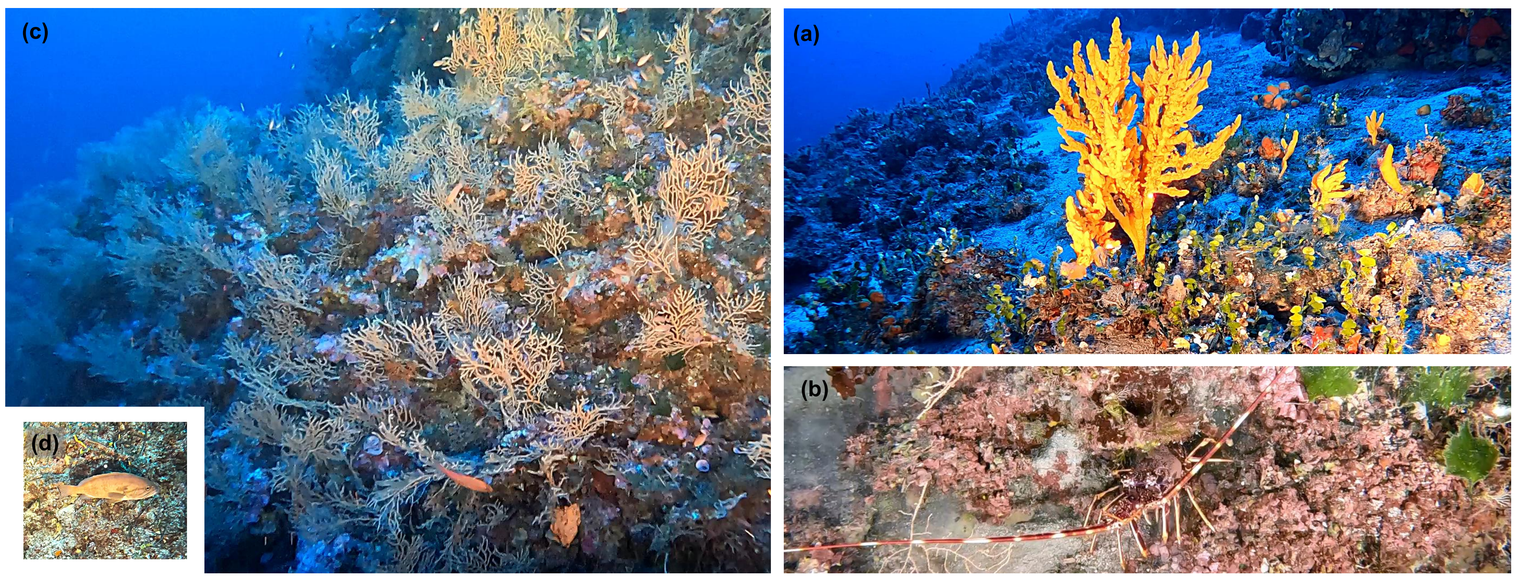

Figure 2: ROV images of Mediterranean coralligenous formations* in the study area and characteristic benthic species, specifically multiple Axinellid sponges (a), a spiny lobster (*Palinurus elephas*) in its crevice made up of encrusting calcareous algae (b), colonies of the yellow gorgonian *Eunicella cavolini* (c), and a young grouper (*Epinephelus marginatus*).

Table 1: Physical and biotic characteristics of the five sites rocky reefs assessed in the NMPANS.

Site	Total area assessed [m²]	Slope (°)	Depth range (m)		Hard substrate (%)	Living cover (%)	Number of conspicuous species [benthic species >1cm height]
			Min	Max			
Moules	508	>80	50	70	80	80	19 [10]
ANE 1	780	>30-80	39	64	90	80	16 [12]
ANE 2	564	>30-80	41	57	90	80	15 [11]
Spilia	530	>80	36	59	95	80	52 [17]
Peristera	906	>30-80	40	71	75	80	30 [20]
Average	658		41.2	64.2	86	80	26 [14]

Table 2: ML characterization in the five sites of MPANS.

Parameter		Total
ML type	Fishing lines	139
	Ropes	19
	Nets	8
	Other	4
ML interaction type	Covering	5
	Entangling	10
	Hanging	144
	Lying	25
ML biofouling stage	0	3
	1	39
	2	26
	3	96
ML removal (%)	0	0
	<50	22
	>50-99	124
	100	17

Table 3: Number of ML items per site and number of gorgonian and sponge colonies interacting with ML items. Square brackets denote number of colonies presenting >10% of injuries.

Site	ML items / m²	ML items / m²	Gorgonians	Massive / Erect sponges
Moules	12	0.02	9[5]	
AEN1	22	0.03	3[3]	
AEN2	44	0.08		1[0]
Spilia	89	0.17	20[20]	23[20]
Peristera	3	0.00	2[1]	

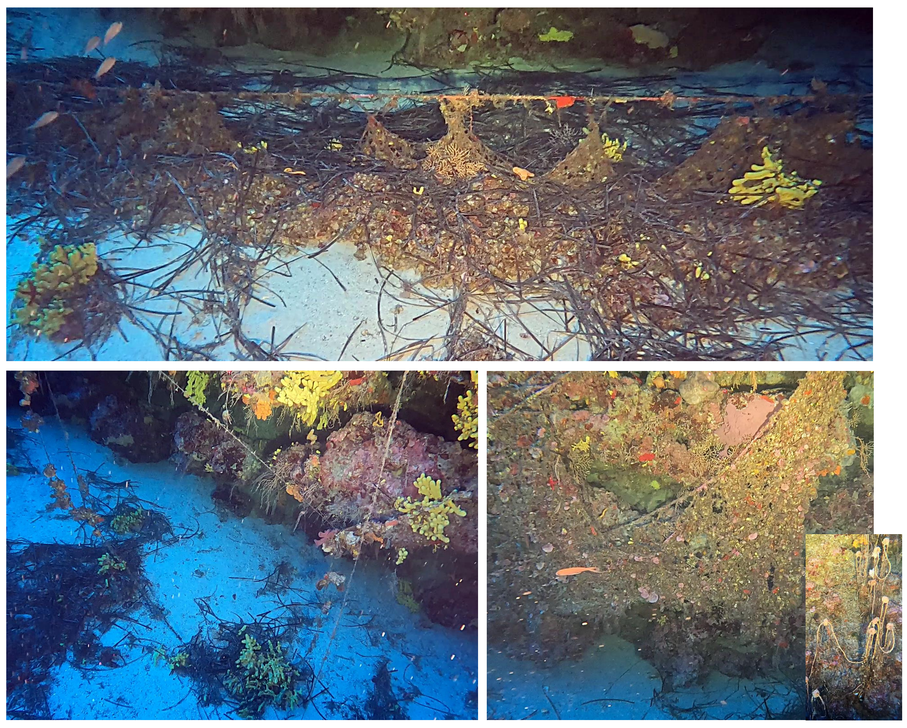

Figure 3: ROV images of marine litter recorded entangling, hanging, covering and lying on mesophotic reefs of the study area. Sponge and gorgonian colonies can be seen fallen on the sandy substrate possibly due to dislodgement by the hanging litter.

Results & Discussion

A total of 3288 m² of rocky reef was surveyed at 40–70 m depth. All sites had intermediate to steep slopes and continuous living **coralligenous formations*** across the full depth range. *(a characteristic biogenic habitat type of the Mediterranean made up primarily by coralline algae)

Overall, 64 conspicuous species were recorded, including six protected sponge species (*Aplysina aerophoba, Axinella cannabina, A. damicornis, A. polypoides, A. vaceleti,* and *A. verrucosa* (Fig. 2a) and seven species of high commercial value, such as the dusky grouper (*Epinephelus marginatus* – Fig. 2b) and the spiny lobster (*Palinurus elephas* – Fig. 2c). The gorgonian *Eunicella cavolini* – Fig. 1d), a key structural species classified as Near Threatened (IUCN), was present at all sites, but was most abundant at Moules, Spilia, and Peristera, while only a few small colonies occurred at AEN 1 and AEN 2.

ML was found at all sites, with a mean density of 0.06 m^{-2}, highest at Spilia and AEN 2 and lowest at Peristera (Table 2, 3). Most litter consisted of lost or abandoned fishing gear, which are commonly entangled on rocky reefs [3]. Much of it was suspended from the reefs, abrading biogenic structures and associated sessile organisms, a problem that likely increases over time as litter becomes heavier through biofouling. Injuries, necrosis, and complete dislodgement of gorgonians and sponges were frequent in heavily impacted areas.

Coralligenous reefs and gorgonians often thrive in areas of strong currents, which also favour litter accumulation. Although ML densities were lower than those reported elsewhere in the Aegean Sea, local hotspots such as the Spilia site, showed clear impacts on habitat-forming species and benthic communities.

These findings provide important evidence on the severity of ML impacts on mesophotic biogenic reefs and support evidence-based management and restoration planning. Within the LifeDream project, the results were used to design a site-specific, risk-based clean-up strategy involving technical diving, and the adoption of passive restoration measures for the most affected areas. Future management actions include monitoring to assess the effectiveness of restoration actions, and measures to minimize the introduction of new ML.

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