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# Integral Health in Messina Strait: marine ecosystems, historical collections and human well-being

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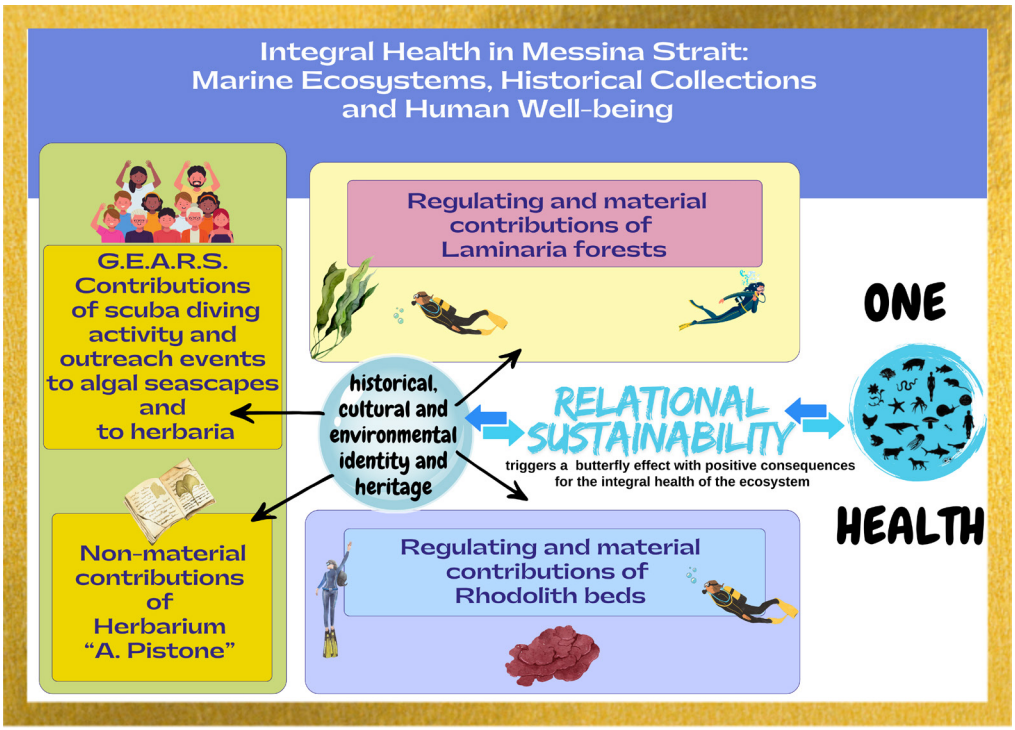
## Highlights

- *The relational sustainability of algal seascapes supports the overall health of marine ecosystems*
- *Laminaria forests and Rhodolith beds offer contributions to native Mediterranean communities*
- *The Herbarium "A. Pistone" offers significant contributions to native Mediterranean communities*
- *Algal seascapes and herbaria support native Mediterranean communities' integral well-being*
- *Scuba diving activities and outreach events' contributions promote the conservation of algal seascapes and the cultural value of herbaria.*

## Graphical Abstract




## Abstract

The benthic ecosystems of the Strait of Messina, *Laminaria ochroleuca* Bachelot Pylaie 1824 forests and rhodolith beds, play a crucial role in promoting environmental and human health, offering essential Nature's Contributions to People (NCP), such as climate regulation, food provision, and psychosocial benefits. Complementing these natural systems, the historical Herbarium "A. Pistone" documents the algal seascapes of the late 19th century and offers cultural, aesthetic, and educational values that enhance psychosocial well-being and strengthen emotional memory within local communities. Sustainable practices, such as scuba diving activities, citizen science initiatives, and awareness campaigns, are proposed as "People's Contributions to Nature" (PCN), expressed through gratitude, empathy, affection, reciprocity, and spirituality. These actions promote mental and physical health by reducing stress, fostering social cohesion, and encouraging active lifestyles, while also supporting nature-based strategies for disease prevention through biodiversity conservation and improved ecosystem integrity. Future research will focus on taxonomic identification of herbarium specimens (using DNA barcoding and morphological analysis), biogeographical and biocoenotic studies, and quantitative assessments of ecosystem services. These analyses are essential to understand how these ecosystems mitigate climate change, reduce environmental health risks, and inform public health policies aimed at integrating ecosystem services into preventive strategies. To strengthen the human–nature relationship and promote integral health, participatory approaches, such as educational workshops, immersive experiences, and collaboration among fishing and mussel-farming communities, local authorities, and schools, are key components of integrated conservation and health promotion frameworks.

**Keywords:** Reciprocal Contributions. Rhodolith Beds. *Laminaria* Forests. Historical Herbarium. Strait of Messina.

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## INTRODUCTION

International agendas such as the United Nations (UN) 2030 Agenda and the European Strategy for 2030 highlight the critical role of nature in promoting physical, mental, and social well-being, especially in the context of global challenges[1,2,3]. Similarly, the World Health Organization emphasizies the importance of preserving ecosystems as a mean of safeguarding human health and well-being[4]. This growing recognition has driven research aimed at exploring the potential of natural environments to positively influence various dimension of health and well-being. Building on this foundation, previous studies have established clear connections between experiences in nature and enhanced psychological well-being, including increased positive mood and reduced negative emotions like anxiety and anger, ultimately contributing to happier and healthier people[5]. These findings emphasise the multidimensional benefits of nature exposure across the lifespan, promoting both mental and physical health for all ages[5]. Marine degradation compromises human health through food chain contamination, biodiversity loss, and pathogen spread[6]. Contact with nature for at least two hours weekly improves physical and psychological well-being[7].

### *Nature's Contributions to People (NCP)*

Conserving kelp forests and rhodolith beds ensures food security, supports disease prevention, and promotes mental health benefits through activities like diving[8,9]. These habitats also sustain fish stocks and provide nursery grounds for commercially important species[10]. The preservation of rhodolith beds and kelp forests is not only an ecological priority but a cornerstone of integral health, linking food security, disease prevention, and human well-being to the resilience of marine ecosystems. Nature's contributions to people (NCP) represent an inclusive framework that includes all the ways in which nature positively or negatively affects human quality of life, whether at the level of individuals, communities or humanity as a whole. The classification of NCP is firmly rooted in the ecosystem services classification developed by the Millennium Ecosystem Assessment[11] which categorized ecosystem services into four main groups: supporting (e.g., nutrient cycling, primary production), regulating (e.g., climate and disease regulation), provisioning (e.g., food, water), and cultural (e.g., aesthetic, spiritual, recreational). Recently, The Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) restructured these four groups into three main groups: regulating contributions which include the functional and structural aspects of organisms and ecosystems that modify environmental conditions experienced by people, and/or sustain and/or regulate the generation of material and non-material benefits; material contributions, referring to tangible elements from nature used for physical needs, e.g., food, energy; non-material contributions, which include intangible benefits affecting psychological and cultural well-being. The coastal marine and brackish/transitional algal seascapes, specifically the Rhodolith beds of Capo Peloro wetlands/lagoon systems and the *Laminaria* forests of the Strait of Messina, along with the specimens preserved in the historical Herbarium "A. Pistone", which serve as evidence of the algal seascapes of the Straits of Messina in the past (late 19$^{th}$ century), represent effective examples of NCP. The Capo Peloro wetlands/lagoon systems have ancient origins and are now protected as both nature reserve and a cultural heritage site due to their traditional shellfish farming practices[12]. The Capo Peloro Lagoon, officially designated as an Oriented Nature Reserve established by the Sicilian Region through a Decree issued on June 21, 2001, is managed by the Regional Province of Messina. Additionally, the area is recognixes as a Site of Community Importance (SCI) under Directive 92/43/EEC and a Special Protection Area under Directive 79/409/EEC and was designated under the Water Project of 1972 by Order No. 1342188 of 07/19/88. The Rhodolith beds (RBs) of Capo Peloro wetlands/lagoon systems and the *Laminaria* forests of the Strait of Messina forms numerous sustainable reciprocal relationships with both the biotic and abiotic environment as well as with the native coastal communities of the Mediterranean Sea. These ecosystems provide essential regulating and material contributions due to their ecological uniqueness within the seascape. Indeed, they generate and sustain meaningful human experiences, support diverse livelihoods and local identity, and provide significant opportunities for research, tourism, and education[13,14,15]. The Herbarium "A. Pistone" primarly contributes through non-material benefits. As a collection of preserved plant specimens, it provides valuable knowledge and information, that support research and education, which are core elements of the IPBES definition of non-material benefits. Herbaria play a key role in understanding biodiversity, conservation, and other scientific and educational purposes, and thus fit within the IPBES definition of non-material contri-

butions. Non-material contributions reflect aspects of cultural identity, spirituality, social cohesion, and moral and social responsibilities toward nature[16]. These elements are closely linked to quality of life, education, artistic inspiration, and the cultural identity of the communities involved. Scuba diving activities further supports human well-being by reducing stress, promoting social bonds and encouraging physical activity.

***People'S Contribution to Nature (PCN)***

At the same time, they also exemplify the concept of People's Contribution to Nature (PCN), a growing framework that complements Nature's Contributions to People (NCP) and it is receiving increasing attention in the academic literature[17,18,19]. PCN includes human actions that influence ecosystems and biodiversity, shaped by local knowledge, values, and practices[20,21]. Scuba diving and outreach activities of native Mediterranean communities, particularly within algal seascapes and through tools such as the Herbarium "A. Pistone", go beyond being simple PCN: they represent reciprocal, affective, and cultural acts that deepen human-nature relationships and promote environmental stewardship. Thus, the main aim of this work is to highlight the NCP of the Rhodolith beds, the *Laminaria* forests and the historical Herbarium "A. Pistone", as well as to suggest a diverse classification of PCN for Scuba diving and outreach activities.

## MATERIALS AND METHODS

The research was carried out using a variety of digital tools to identify and download relevant bibliographic sources. Specifically, the following resources were employed:

- Bibliographic databases, which provide references, abstracts, and sometimes links to original documents.
- Full-text databases, offering access to complete publications.
- Citation databases, such as Scopus and Web of Science, which allow the analysis of citation networks and the scientific impact of articles.
- Search engines and open-access repositories, enabling access to freely available content.
- Academic and professional platforms, including ResearchGate and LinkedIn, useful for retrieving articles, connecting with authors, and accessing shared materials.

The search strategy considered all relevant terms, such as author names, keywords, and titles. These terms were progressively refined using suggestions generated by the tools themselves, with the aim of improving both the relevance and the quality of the results obtained.

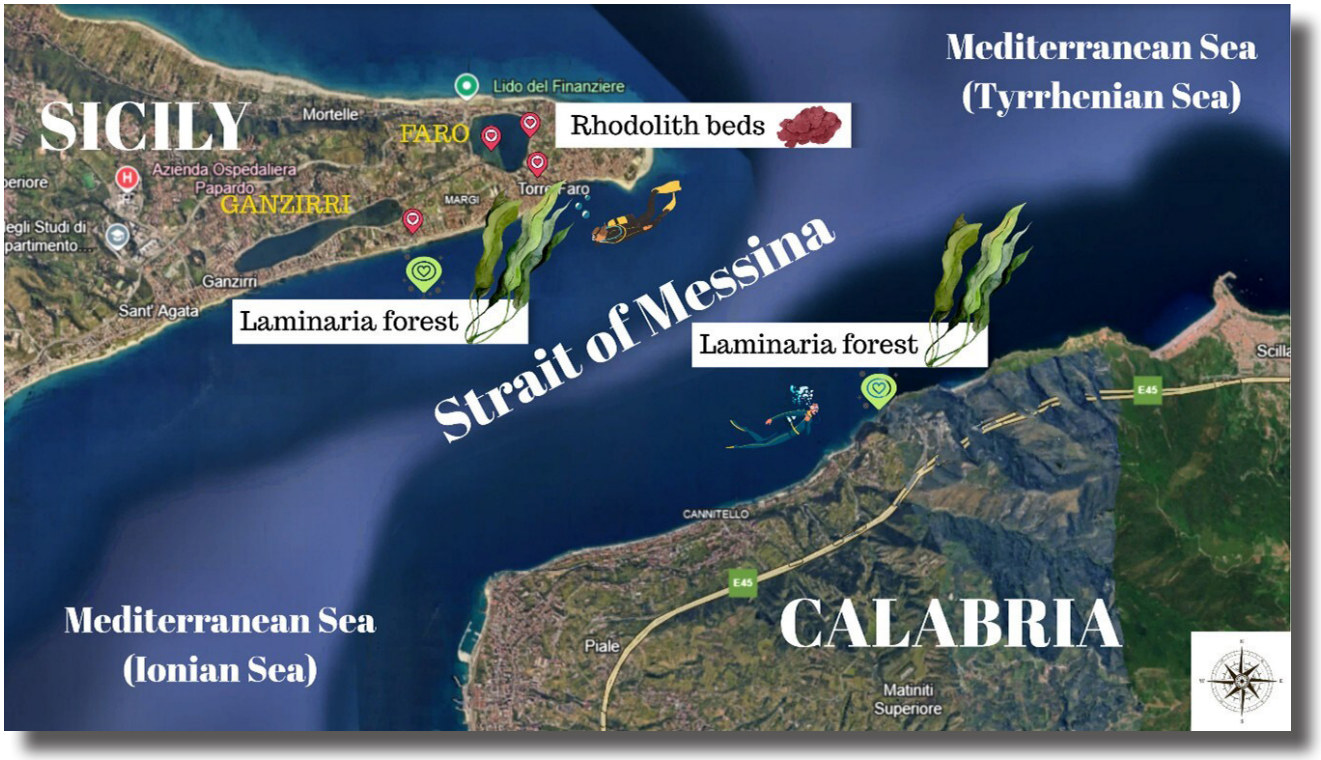


**Figure 1 -** Location of *Laminaria ochroleuca* forests and rhodolith beds (Strait of Messina - Capo Peloro wetlands/lagoon systems).

The classifications used to describe the NCPs provided by Rodoliti beds, *Laminaria* forests, and the Herbarium "A. Pistone" (Figure 1, 2) are based on the Millennium Ecosystem Assessment[11] and the Global Assessment on Biodiversity and Ecosystem Services (IPBES)[22].

**Figure 2 -** The Herbarium "A. Pistone".

In addition, an introductory assessment of the Herbarium "A. Pistone" was conducted in four main phases: (i) recovery-cataloging-preservation; (ii) historical research; (iii) digitization; and (iv) preliminary taxonomic updating, the latter carried out using AlgaeBase and the World Register of Marine Species (WoRMS). Regarding the reciprocal contributions of scuba diving activities and outreach events to algal seascapes and herbaria, we propose a new PCN classisification called G.E.A.R.S. Contributions (Contributions of Gratitude, Empathy, Affect, Reciprocity and Spirituality). Unlike the economically focused PCN classification used by Madrigal-Martínez[23], this new classification is based on the following gift categories: contributions of gratitude; contributions of empathy; contributions of affect (emotions); contributions of reciprocity and contributions of spirituality (Table 1).


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**Table 1 -** People's Contributions to Nature (PCN): Madrigal-Martínez's classification and G.E.A.R.S classification.

| Economically focused | | Gift and gratuitousness focused | |
|---|---|---|---|
| Madrigal-Martínez: nature cannot be conserved or used sustainably without collaborative governance that engages people and institutions at all levels, combining top-down and bottom-up approaches. Planning contributions to nature can only be done with governance, as the planning process involves many stakeholders and individual citizens. | | Giaccone-Mannino-Ragazzola (G.E.A.R.S): this perspective acknowledges that humans contribute through emotional and ethical gifts such as gratitude, empathy, affection, reciprocity, and spirituality to the weel-being and health of the nature. These contributions foster relational sustainability and reciprocal care between humans and the natural world. | |
| 1 LEVEL | Direct contributions rely on the fact that individuals must be able to provide help to achieve nature's goals without an intermediate, and indirect contributions refer to humans that are in a position to help nature but there is no possibility for a direct reciprocation. | GRATITUDE | Actions, attitudes, and demonstrations of appreciation by the native Mediterranean people towards nature. |
| 2 LEVEL | Resources of contributions are tangible and intangible | EMPATY | Motivational empathy manifests itself when the experience of empathising with nature that is suffering ("feeling inside, feeling on one's own skin") leads to helpful behaviour. |
| 3 LEVEL | Type of resources are financial and physical (tangible), social and human (intangible). | AFFECT (EMOTIONS) | The most effective emotional contributions to the environment are those that, in a communal and shared manner, allow us to experience emotions and affection towards nature. |
| 4 LEVEL | Functionality of the contributions are (Broad Scope): management, restoration, protection and enhacement | RECIPROCITY | Every organism, whether living or not, embodies relationship, reciprocity, and care. Through these connections, each can both give and receive care, contributing to a shared sense of well-being on both a personal and planetary scale. |
| 5 LEVEL | Functionality of the contributions are (Specific scope): biodiversity, wild species, invasive-alien species, other | SPIRITUALITY | Many spiritual traditions emphasize the interconnectedness of all things, fostering awareness of human impact on the environment and a sense of shared responsibility for future generations. |

## RESULTS

The study clearly highlighted how benthic habitats such as Rhodolith beds (RBs) and *Laminaria* forests are able to provide crucial ecosystem services with direct implications for environmental and human health, primarily through essential regulatory functions (regulating and material contributions). Instead, the historical Herbarium "A. Pistone", which documents the algal biodiversity of the Strait of Messina in the late 19$^{th}$ century, offers cultural, aesthetic, and educational values that contribute to the psychosocial well-being of local communities (non-material contributions). The "Nature's Contributions to People" (NCP) of RBs, *L. forests* and the Herbarium "A. Pistone" are evidenced by their peculiar roles, precisely the ecological and historical significance of these algal seascapes and the herbarium's role as a mediator of emotional memory and a mean of valorization of traditional scientific knowledge. Sustainable activities, such as scuba diving and outreach initiatives with native Mediterranean communities, were also described as form of PCN, exemplified through the description of G.E.A.R.S. contributions.

### *Rhodolith beds*

Rhodolith beds (Figure 3), formed by free-living non-geniculate coralline algae, are globally recognized as important marine benthic habitats with both ecological and socio-economic importance. However, these habitats are increasingly threatened — especially from human activities[24]. Despite their broad distribution, ecological roles and biodiversity, rhodolith beds remain under-researched, thus limiting effective conservation efforts[25]. These habitats are mostly studied in the circalittoral zone, where low light levels and reduced competition from green and brown algae create favourable condition to their development[26]. Shallow-water and brackish rhodolith beds, however, remain poorly investigated. Patchy rhodolith beds have been identified in the Faro Marshes/Lagoon, where traditional clam farming practices disturb sediments, inhibit mud deposition, and promote bioclast accumulation, facilitating rhodolith formation[27]. In the connecting canals, strong tidal regimes enhance water exchange and nutrient flow, further supporting rhodolith growth. The dominant coralline

algal species in these environments include *Neogoniolithon brassica-florida* (Harvey) Setchell et L.R. Mason, *Neogoniolithon hauckii* (Rothpletz) R.A. Townsend et Huisman and *Phymatolithon lenormandii* (Areschoug) W.H. Adey[27]. These calcareous algae play a regulatory role in carbon cycling, with carbon fluxes influenced by community productivity and the balance between autotrophic and heterotrophic organisms[28,29]. Rhodolith beds contribute to climate regulation by acting as carbon sinks when photosynthetic $CO_2$ uptake exceeds respiratory losses[30].

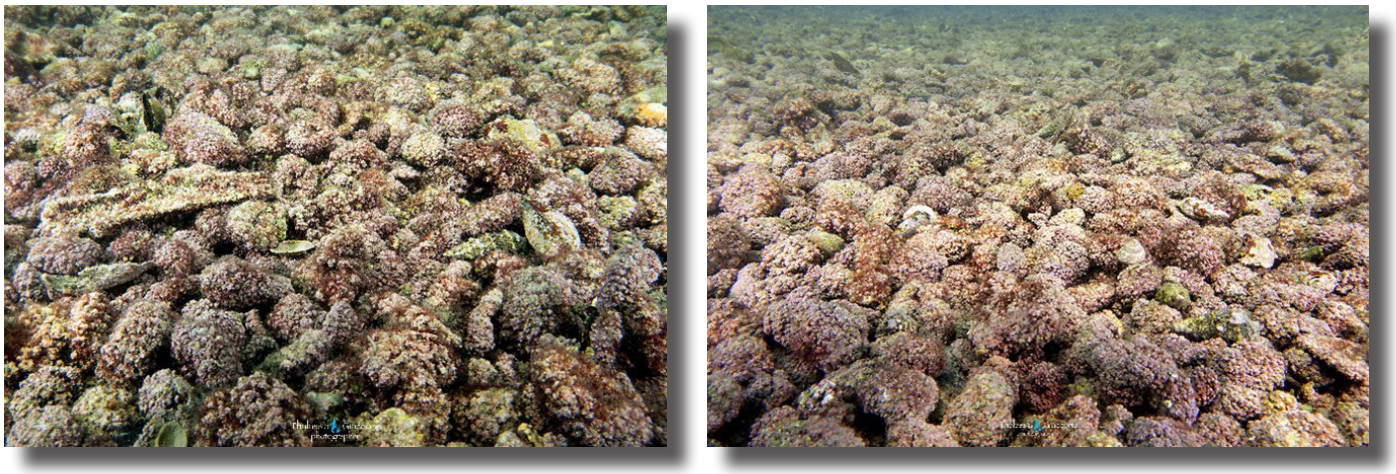

**Figure 3 -** Rhodolith beds (Ionian Sea).

Recognised as ecosystem engineers[31], rhodoliths enhance habitat complexity and primary production, offering niches for a wide reange of marine life, including macroalgae and invertebrates[32]. They are considered biodiversity hotspots[24,27,32] and function as corridors for genetic and ecological connectivity with other marine habitats[24,33]. Rhodolith beds hold significant pharmacological potential, with bioactive compounds showing hypolipidaemic, antioxidant, immunological, antitumoural, antiviral, and antibacterial properties[34]. These ecosystems provide regulating contributions (regulating ecosystems services) and material contributions (provisioning ecosystems services) thanks to their ecological uniqueness within the marine seascape. Their ecological importance and vulnerability have been recognized in various European and international conservation frameworks[35,36,37,38] leading to protection initiatives in several countries including France, Spain, Italy, Malta, and Greece[39]. The Mediterranean Action Plan under the United Nations Programme also includes specific measures for their conservation[36,40].

***Laminaria forests***

Submerged forests of *L. ochroleuca* (Figure 4) represent highly productive marine ecosystems with significant roles in carbon cycling and climate regulation. These macroalgae exhibit high primary productivity, converting atmospheric $CO_2$ into organic carbon through photosynthesis, thereby contributing to local carbon sequestration and mitigating climate change effects. In the Strait of Messina, this process is further enhanced by upwelling currents that support phytoplankton blooms, thereby increasing $CO_2$ absorption[15]. The structural complexity of *Laminaria* rhizoids creates a stable and protective habitat for diverse assemblage of interstitial fauna, including copepods, polychaetes, gastropods, amphipods, bryozoans, bivalves, and sponges. These organisms are sensitive to environmental stressors such as turbidity, hydrocarbon pollution, and sewage discharge, making them potential bioindicators of coastal ecosystem health. *Laminaria* forests act as ecosystem engineers. Their large thalli attenuate wave energy, reduce sediment resuspension, and increase substrate stability. The associated flora includes both soft and calcareous algae, with species-specific affinities that influence forest persistence. Epiphytic communities on stipes and laminae exhibit vertical zonation pattern driven by light gradients, with biomass decreasing with depth. High epiphyte loads may indicate environmental stress, such as thermal anomalies or eutrophication. The invasive bryozoan *Membranipora membranacea* (Linnaeus, 1767) is frequently associated with *Laminaria* fronds, likely due to its flexible growth morphology. While direct herbivory on fronds is limited, tissue weakening may predispose forests to storm-induced defoliation. These brown algae form dense underwater aggregations, that can develop into either upright forests on rocky substrates or prostate beds on mixed substrates. In the Mediterranean such formation represented by genera including *Laminaria*, *Phyllaria* and *Saccorhiza*. *Laminaria ochroleuca* forests are rare in


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the region, known to occur only in the Alboran Sea and the Strait of Messina. In October 2022 and in January 2023, a forest of *L. ochroleuca* was discovered on the Messina side of the Strait of Messina (38°15′31.24′ N,15°37′54.58′ E), extending from 40 to at least 60 m depth[15]. Subsequently, in October 2023, a forest and a bed of *L. ochroleuca* on the Reggio Calabria side of the Strait of Messina were found at Porticello (Scylla, 38°14′45"N – 15°40′39"E), between 48 to 55 m depth, thought they appear they extend even deeper[41]. These kelp forests are resilient and relational, fostering sustainable interactions with the surrounding environment and native Mediterranean biota. They provide a wide range of ecosystem services, including habitat provision, coastal protection, and support for fisheries, research, and education[15,41].

**Figure 4 -** *Laminaria ochroleuca* forests (Strait of Messina).

These contributions thus fit within the IPBES definition of regulating and material contributions. *Laminaria ochroleuca* is a strictly protected species listed in Annex I of the Bern Convention on the Conservation of European Wildlife and Natural Habitats. According to protocol SDM/3/6259 of 30 July 2003, it is considered a habitat of priority interest (IV. 3. 1. 8).

***Herbarium "A. Pistone"***

Antonio Pistone, first assistant to the Chair of Botany of the Royal Botanical Garden of Messina and referent of the Ornithological Cabinet of Messina in the late 1800s, authored several scientific publications. In addition to his written work, he created an Algae Herbarium of the Strait of Messina, hypothetically related to his collaboration with Antonino Borzì, chair of botany since 1879 in the Royal University of Messina. It is plausible that Borzì asked A. Pistone to create a Mediterranean Algae Herbarium and in particular an Algae Herbarium of the Straits of Messina, as a further contribution to the expansion of the scientific collections of the Royal Botanical Garden of Messina. The Herbarium "A. Pistone" consists of five volumes containing herbarium sheets, most of which are labeled with Latin names, collection sites (e.g., Ganzirri and Faro Lagoons, Port of Messina), dates, and the name of the collector. The sheets are well-preserved and stored in decorative cardboard cases. Each sheet includes a Roman numeral, dried algal specimen, and a label with taxonomic data, mostly handwritten by Pistone in 19th century script. Some labels are printed and trace back to the Royal Botanical Gardens of Messina. The herbarium is incomplete, with missing parts and no known explanation for the gaps. Historical research suggests a working relationship between Pistone and Antonino Borzì but no further bibliographic records on Pistone has been found. To better identify the collection sites, historical and current place names were compared using an 1864 English map of Messina published in Murray[42]. This analysis clarified several collection sites: "Messina Lanterna" likely refers to Lanterna S. Raineri; "S. Salvatore" to the Santissimo Salvatore Castle, both located in the Falcata area; "Messina" may indicate coastal areas near the harbor; "Mare Grosso" likely correspond to the current site in the Cannamele Ward and "Lidi Faro" probably indicates the Capo Peloro and Faro coastline. Some specimens are associated with locations such as Genova, Lampedusa, and parts of Africa, possibly visited during Pistone's travels. Digitisation and a creation of a dedicated database aim to facilitate consultation and ensure the preservation of the collection. Although not yet publicly accessible, the Excel-based database currently supports scientific research and floristic updates[43]. The herbarium includes 126

specimens, of which 124 marine and 2 freshwater, primarly belonging to the phyla *Rhodophyta* (101 specimens), *Chlorophyta* (16 specimens), and *Phaeophyceae* (6 specimens). Taxonomic updates based on AlgaeBase and WoRMS yielded mixed results: while some outdated names were traceable, others remain unresolved and may require DNA barcoding for accurate identification. One specimen could not be identified due to illegible handwriting. The historical Herbarium "A. Pistone" provide non-material contributions to Mediterranean communities, offering cultural values (such as sense of belonging, identity and self-understanding, support), aesthetic value (including emotional well-being, personal growth, nature connection), and educational value (such as empowerment, mental health awareness, capacity building). These values are fundamental to the psychosocial well-being of communities themselves. Beyond its cultural and scientific significance, the herbarium holds ecological and paleo-ecological value. Natural history archives of marine algae, like this collection, can contribute to reconstructing past environmental conditions to complement and extend instrumental records. Algal herbaria serve as primary resources for studying past biodiversity and comparing it with present-day data to to assess changes driven by climate changes or human activities. Ultimately, the herbarium function as a vessel of emotional memory and an instrument of preserving and valorizing traditional scientific knowledge.

***Scuba Diving Activities and Outreach Events***

The definition and characterization of "People's Contributions to Nature" (PCN) has been revised to incorporate the dimension of "gift-giving." Drawing inspiration from indigenous worldviews and scholar such as Kimmerer[44], this perspective acknowledges that while humans may luck the ability to offer nature's biological gifts (e.g., photosynthesis), they contribute through emotional and ethical gifts such as gratitude, empathy, affection, reciprocity, and spirituality. These contributions foster relational sustainability and reciprocal care between humans and the natural world. Sustainable activities, such as scuba diving and outreach initiatives led by native Mediterranean communities, serve as an example of PCN. To better describe and categorize these contributions, we propose a classification framework, called G.E.A.R.S, an acronym Gratitude, Empathy, Affection, Reciprocity, and Spirituality. These dimensions reflect the ways in which native Mediterranean people give back to nature, particularly in relation to the RBs, *Laminaria* forests, and the Herbarium "A. Pistone".

***Contributions of gratitude***

Gratitude is both a feeling and a state of mind that involves affection towards those who have done us good, remembrance of the benefit received and the desire reciprocate it. In this context, Contributions of gratitude refers to actions, attitudes, and expression of appreciation demonstrated by the native Mediterranean communities towards nature, particularly, the marine environment of the Strait of Messina and the Capo Peloro wetlands/ lagoon systems during scuba diving activities and outreach events.

***Contributions of empathy***

Empathy is both the ability to understand another person's mental and emotional state immediately and without the need for verbal communication. It also encompasses phenomena of deep participation and identification through which aesthetic and emotional understanding of nature is achieved. In particular, motivational empathy arises when the experience of empathising with nature's suffering ("feeling it within onself") inspire compassionate and helpful behaviour. This motivating force emerges from sharing the distress of other species inhabiting the Mediterranean. Act such as underwater and beach clean-up, or workshops on waste reuse during outreach events, not only foster a sense of well being in the empathethic individual but also contribute to the health and resilience of the individual with whom they empathize, in these case, marine vegetation.

***Contributions of affect (emotions)***

Emotion is the fundamental sense of feelings, ranging from unpleasant to pleasant (valence) and from passive to active (arousal). Etymologically derived from *emovere* - "to set in motion", emotion denotes a complex reaction involving physiological changes from a basic homeostatic state, accompanied by subjective experiences (feelings), and often expressed through mimic behaviour. Consider the range of emotions experienced by scuba divers as they explore a *Laminaria* forest or glide over on a bed of Rhodoliths, or the feeling evoked in citizens who, through outreach activities encounter and observe anthropological artifact such as a historical herbarium that narrates stories of the sea and humankind from a bygone century. These emotional responses illustrate the profound effective bond between humans and nature, an essential dimension of people's contribution to the natural world.

***Contributions of reciprocity***

Everything on Earth is interconnected through

reciprocal relationships. The term reciprocity, from the Latin *reciprocus*, evokes the idea of flow and return, of mutual exchange. The principle is evident in the movement of elements such as carbon and oxygen which circulate continuously between living and non-living systems. Such as interconnectedness exists in both states of health and illness, comfort and discomfort. Relational sustainability — the practice of nurturing of sustainable, reciprocal relationships — is therefore essential to maintaining global balance and harmony. It emphasizes mutuality between humanity and the planet, encompassing all living and non-living beings. Every organism, whether living or not, embodies relationship, reciprocity, and care. Through these connections, each has the capacity to give and receive care, contributing fostering well-being on both personal and planetary scales.

***Contributions of spirituality***

Spirituality can inspire and motivate nature conservation by recognizing the intrinsic value of nature, its essential role in human life, and the presence of a divine or spiritual energy in all biotic and abiotic elements. Many spiritual traditions highlight the interconnectedness of all things, fostering awareness of humanity's impact on the environment and a sense of shared responsibility for future generations. Modern natural sciences, especially in conservation, are increasingly exploring whether true ecology is possible without acknowledging the metaphysical-spiritual dimension of nature.

## DISCUSSION

***Interconnected relationships and the "one health" framework***

The reciprocal and interconnected relationships among the regulating, material and non-material contributions of marine algae seascapes, historical algae collections, and G.E.A.R.S. initiative arising from scuba diving activities and outreach events, generate cascading (or butterfly effect) effects that enhance overall ecosystem health. Native Mediterranean communities are among the many beneficiaries of these dynamics. The well-being of individual species intrinsically reflects the well-being of the entire ecosystem[15]. The concept "One Ocean, One Health" highlights the interdependence between human, animal and environmental health[15]. Collaborative improvements in these dimensions can foster a more sustainable and resilient planet. This holistic "One Health" framework, endorsed by the Italian Ministry of Health, the European Commission and various international organisations, is recognized as a cross-disciplinary strategy addressing the health needs of all population, including the most vulnerable. It integrates behavioural, socio-economic, cultural, and environmental determinants, encompassing living and working conditions. This comprehensive perspective provides an effective foundation for disease prevention, treatment, and health promotion at both individual and population level[15]. The One Health approach also recognizes that efforts to protect human, animal, and ecosystem health should be coordinated to benefit all. In contrast to health threats (storms, seafood contamination, harmful algal blooms, occurrence of toxic chemicals and pathogenic microorganisms) the ocean also provides great promise for health benefits through high quality food sources and development of new pharmaceuticals. Climate changes are affecting the balance of ocean-related risks and benefits. This holistic approach could be a transdisciplinary tool for formulating solutions or processes to complex issues affecting the overall health of ecosystems and people.

***Ecosystem services and cultural contributions***

*Laminaria* forests and Rhodolith beds provide critical regulating and material ecosystem services, including oxygen production, $CO_2$ sequestration, coastal protection, nursery role for fish species and potential pharmacological applications. Complementairly, the Herbarium "A. Pistone" offers non-material contributions: it serves as a repository of historical biodiversity data, enabling comparisons with present-day assemblages and facilitating assessment of climate-driven changes. Moreover, it functions as an emotional and cultural archive for divers and marine enthusiasts. These contributions exemplify the notions of gift and communion of goods, grounded in repicprocity and gratitude. Nature offers itself freely to the Mediterranean communities, which in turn respond through care, empahty and spiritual connection. This exchange represents a "gift on the plane of being", an anthropological concept that transcends both individualism and collectivism, promoting a deep relational dialogue between humans and nature. Marine degradation directly impacts human health[6]. A 2019 study found that spending at least two hours a week in contact with nature is the minimum amount of time needed to "feel good", i.e. to reap benefits in terms of both health and general wellbe-

ing[7]. The conservation of rhodolith beds and kelp forests could therefore therefore provide multiple benefits. Motivations to dive in kelp include observation, being in nature, relaxation and escape, adventure and exercise, discovery and learning, and photography. Reported experiences while diving in kelp forests include relaxation and wellbeing, awe and wonder, contact with nature, freedom, novelty, feeling of safety, and social interaction. Divers ascribed extrinsic and intrinsic values to kelp and recognised ecosystem services of kelp forests[8]. Exposure to outdoor blue spaces can help improve human health by reducing stress, promoting social relationships, encouraging physical activity and supporting mental well-being[9]. Kelp forests support wildlife populations of high socio-economic value[10]. The main threats and forms of degradation (heat waves, decline in natural predators of herbivorous species, changes in salinity, acidification, water turbidity, changes in current intensity and direction due to human maritime activities, etc.) can lead to a reduction in fish stocks, and therefore their conservation is essential for food security. Rhodolith beds also promote the formation of shelters, reproduction sites and food availability for other species; they serve as "nursery" substrates for many commercially important fish, as well as molluscs and crustaceans. The historical algal collection in the Herbarium "A. Pistone" embodies the wonder of the early naturalists: each specimen, carefully collected, dried, and annotated, represents an act of stewardship toward the sea. Today, divers experience similar wonder as they encounter underwater shapes and colours. Both transform the invisible into a narrative, one through preserved specimens, the other through images and video. The herbarium thus stands as an archive, the diver as a living witness. Together, they trace a continuum linking past and present, memory and experience, conservation and contemplation — an ongoing dialogue between those who once observed and those who continue to observe, united by the same sense of wonder. Ultimately, the Herbarium "A. Pistone" constitutes not only an environmental and cultural asset but also an instrument of emotional memory, evoking the positive sensations associated with diving and marine exploration. The enduring connection between past naturalists such as Antonio Pistone and present-day divers reflects two complementary perspectives bound by shared values of care, curiosity, and reverence for the marine environment (Table 2).

**Table 2 -** Approaches to Marine Biodiversity: Naturalists of the past and Divers of today (place: Strait of Messina, date: 2023-2025, source: historical naturalist practices documented in marine biology archives and modern practices recorded during citizen science and outreach initiatives).

| Naturalists of the past | Divers of today |
|---|---|
| Collect, dry and store | Observe, photograph, share |
| Record data and locations | Geolocate and document conditions |
| Classify and interpret biodiversity | Raise awareness and support conservation |
| Act out of amazement and a desire for knowledge | Act out of amazement and a sense of responsibility |
| Feel excited while studying and observing marine organisms | Feel excited as they leaf through the herbarium and remember the marine organisms they observed during their dives |

The mutual exchange between the Herbarium 'A. Pistone' and the native Mediterranean communities is, above all, an exchange of emotions.

***Health benefits through emotional intelligence and gratitude: a framework for sustainability***

The profound influence of emotions on memory is fundamental to the human capacity to translate affective experience into thought and behaviour, thus triggering sustainable lifestyles and actions grounded in care and respect. Sustainable behaviour arises from positive emotions, while a sustainable lifestyle is rooted in attitudes of care and respect. The direct health benefits of contributions are shown in Table 3.

**Table 3 -** Regulating, material, non-material and G.E.A.R.S contributions: direct health benefits.

| Category | Direct Health Benefits |
|---|---|
| Regulating | • Carbon and nutrient sequestration: kelp forests absorb $CO_2$ and excess nutrients → cleaner air and water → reduced risk of respiratory diseases and waterborne illnesses.<br>• Coastal protection: wave energy reduction → less storm damage and lower exposure to contaminants after floods.<br>• Calcium carbonate production and carbon storage of rhodolith beds → buffers ocean acidification → healthier marine environment → lower risk of waterborne diseases.<br>• Sediment stabilization and filtration of rhodolith beds → clearer waters for safe bathing and drinking. |
| Material | • Seafood from kelp-associated fisheries → rich in omega-3 fatty acids → supports cardiovascular health.<br>• Bioactive compounds from kelp (e.g., alginates) → used in nutraceuticals and medical applications.<br>• Support of rhodolith beds for benthic biodiversity and fisheries → provides high-quality protein and micronutrients → improves nutrition and food security.<br>• Bioprospecting: compounds from coralline algae and associated microbiota → potential biomedical applications. |
| Non-material | • Promotes environmental literacy and sustainable practices → indirectly supports public health by reducing pollution and ecosystem degradation.<br>• Exposure to natural history collections (herbarium) can reduce stress, enhance curiosity, and improve psychological well-being (emotional memory, evoking the positive sensations associated with diving and marine exploration). |
| G.E.A.R.S. | • Stress reduction: scuba diving in "blue spaces" lowers cortisol and anxiety.<br>• Mindfulness and relaxation: underwater breathing and sensory focus promote calmness.<br>• Improved mood and resilience: contact with nature enhances emotional well-being.<br>• Physical activity: contributes to overall mental health through endorphin release.<br>• Social connection: fosters sense of belonging and community engagement.<br>• Environmental awareness: increases purpose and positive emotions.<br>• Cognitive stimulation: learning about marine life boosts curiosity and mental agility.<br>• Empowerment: active participation in conservation improves self-esteem and life satisfaction. |

Neuroscientific evidence indicates that human decision-making is primarily driven by emotions and common senseprocesses that do not stand in opposition to logical reasoning but complement it. Common sense guides behaviour in context-specific situations, while emotional information attributes value to experience by signalling its relevance or urgency. Without these mechanisms, the human brain would be overwhelmed by excessive, unfiltered data, leading to slower, less adaptive responses in an ever-changing environment. Emotions therefore play a crucial regulatory role, allowing individuals to assign positive or negative valence to perceived reality and to act accordingly. The reality we experience derives its meaning from an intricate interplay between past and present emotions. This reciprocity on the emotional level can therefore enable the development and affirmation of the ecological, emotional and social intelligence described by Goleman[15]. Emotional intelligence, in particular, provides tools to recognise and manage one's own emotions, understand those of others, and cultivate within mutual support in communities and between humans and nature. Such emotional attunement can strengthen collective resilience in the face of climate change and environmental uncertainty. As economist Bruni L.[45] observed: "*Gratitude is [...] a dimension that can accompany any action. For this reason, it is not gratuitous, but rather its opposite, since gratitude is not a price equal to zero, but an infinite price, to which one can only respond with another act of gratitude*." Gratitude therefore transcends the logic of the market exchange, consumerism and individualism and instead opens pathways toward sharing, sociality, fraternity and, above all, a renewed culture of giving and self-giving[46]. Although native Mediterranean communities do not possess the extraordinary capabilities of other species (such as photosynthesis or carbon sequestration), they hold a unique and essential gift: gratitude. This sentiment is not merely a benign emotion but a transformative force. Expressing gratitude means recognising the gifts we have received and those who have given them to us, that is, recognising all the NCPs of the algal marine seascapes and the Herbarium "A. Pistone". Gratitude challenges the notion of human exceptionalism and instead promotes respect for all forms of life[46]. Gratitude also carries evolutionary and ecological significance. It fosters self-control, satisfaction and resistance to consumerism reinforcing sustainable values and behaviours. Indigenous cultures, through their narratives and tradition, have long warned against forgetting gratitude, which leads to both spiritual and material imbalances[46]. Extending such gratitude protocols to the Mediterranean Sea, its algal seascapes, and the Herbarium "A. Pistone", entails acknowledging that every gift received from nature carries an inherent responsibility to give back. This principle of reciprocity is the basis of ecological balance: giving and receiving sustain the harmony in life[41]. Relational sustainability, founded on reciprocity and gratitude, is therefore the necessary condition for balance and harmony across both Mediterranean and global scales.

## CONCLUSIONS

***Holistic integration for marine and human health***

The integration of ecological, emotional, spiritual and social dimensions represents a fundamental step toward a holistic understanding of the health of marine seascapes and humans. The Herbarium "A. Pistone" and the algal seascapes of the Mediterranean Sea function as complementary repositories of scientific and emotional knowledge, linking past and present through observation, care, and wonder. This dynamic interaction exemplifies relational sustainability, in which ecosystems and human communities co-evolve through reciprocity and shared responsibility. Recognising the intertwined roles of Nature's Contributions to People (NCP) and People's Contributions to Nature (PCN), this study highlights that emotional and spirtual engagement is central to conservation and health promotion. These contributes act as cognitive and motivational drivers for sustainable behaviour and mental well-being. Neuroscientific evidence confirms that such engagement reduces stress, fosters resilience, and encourages active lifestyles, directly supporting mental and physical health. From a policy perspective, integrating ecosystem services into public health strategies can improve environmental quality, mitigate climate-related risks, and strengthen community-based resilience. Protecting Mediterranean marine habitats through initiatives such as SPAMI (Specially Protected Areas of Mediterranean Importance) and participatory conservation projects aligns with nature-based disease prevention, reducing exposure to pollutants and supporting food security.

***"One health" in action: education and community engagement***

To implement the 'One Health' approach in native Mediterranean communities, an immersive and interactive sea room should be created. This space would allow students to virtually experience scuba diving in the *L. ochroleuca* forest and Rhodolith beds using 360° visors, thus fostering an emotional and empathetic connection with marine biodiversity. Educational workshops for students and their families would follow, promoting sustainable lifestyles. Fishing communities would also be involved in raising public awareness of sustainable fishing practices and the economic benefits of protecting the nurseries hosted by the *Laminaria* forests in the Strait of Messina. Similarly, mussel farming communities in the Capo Peloro wetlands/lagoon systems would be involved in increasing collaboration on monitoring Rhodolith beds. The municipalities and coastal provinces of Sicily and Calabria could stipulate territorial agreements to counter threats to the forests, and to combat coastal building abuse, illegal waste disposal, and malfunctioning water purification systems along Capo Peloro wetlads/lagoon systems. Local administrations, the Coast Guard, environmental and diving associations, researchers, and schools could collaborate on beach and seabed clean-ups, monitoring surveys, and participatory science projects. Divers could receive specialized training and certifications in participatory science. Ultimately, fostering relational sustainability means moving beyond anthropocentric views to embrace an ethics of reciprocity. Co-responsibility and co-participation should guide both scientific practice and societal action. Through this integrated approach, the "One Ocean, One Health" vision becomes not only an ecological imperative but also a public health strategy, promoting biodiversity, cultural heritage, and human well-being in synergy.


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The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the workreported in this paper.

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