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Review

Promotion of Paleontological Heritage: Case Histories from Southern Italy

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Abstract: The preservation of paleontological heritage is relevant for paleobiological and geological research, as well as for scientific dissemination. Fossils are indicative of the evolutionary processes, biodiversity, ecology, and geography of the past and require specific geoconservation actions. In Italy, fossils are protected as cultural heritage, and their unauthorized collection and trading are counteracted by a regulatory framework. The local superintendence and law enforcement provide control over the territory, often resorting to the expertise of university paleontologists. In the Calabria region (southern Italy), the collaboration among institutions is yielding interesting results in research, preservation, and public awareness of paleontological heritage. This paper highlights the different approaches to the conservation and promotion of fossils by three museums in Calabria. At the National Archeological Museum of Reggio Calabria, fossils are included in the Prehistory section. The history of life on Earth, with a focus on regional paleontology, characterizes the Museum of the University of Calabria. The Civic Museum of Ricadi exhibits local fossils. Collaboration among these museums and their institutional referents contributes to public awareness and scientific understanding of paleontological heritage, reinforcing the need for conservation and promotion strategies.

Keywords: fossils; museum; protection; legislation

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1. Introduction

The importance of fossils as heritage to be preserved is exemplified in the notes of Noffke [1]: "The fossil record is provided by million-year-old rocks, which constitute an archive of ancient life in former and unfamiliar environments". Fossils reflect ancient life forms, and the paleontological heritage they represent mirrors the biodiversity of the Earth's past [2]. Due to the dynamic and interactive nature of fossilization, each fossil is inherently unique and unrepeatable, making it a valuable asset [3,4]. According to Endere and Prado [5], "the statement that fossils are non-renewable scientific resources is the main justification for their protection and the reason for being considered part of our shared heritage". Therefore, like exceptional landforms, the fossil record is an integral part of the Earth's geological heritage, offering crucial evidence of its palaeobiological history and necessitating geoconservation efforts [6–8]. For these reasons, like other aspects of the

planet's geodiversity, paleontological heritage should be subject to geoconservation efforts from a protective standpoint, but this is a challenging task due to the nature of the fossil record. Some geosites, such as petrified forests or Fossil-Lagerstätten, owe their existence to their fossil content. Most of these sites are protected by law and integrated into appropriate geoconservation infrastructures, such as national parks, geoparks, and museums, and various site-based evaluation approaches have been proposed by different authors and organizations [9]. The International Paleontological Association supports PaleoParks, which seek to identify and protect important endangered fossil sites worldwide, whether they are already preserved or not [10,11].

The fossil record of the Earth, however, is not limited to the specific locations where fossils remain in situ. In many cases, the location is less important than the material it yields, particularly in the case of fossil sites that are currently inaccessible or only temporarily exposed [12,13]. Historically, many of these sites provided crucial reference collections, which are now stored elsewhere. These collections often include unique fossils that were removed during expeditions organized by major overseas museums, mostly in the nineteenth century [14]. Henriques and Pena dos Reis [15], utilizing an Integrated System for Qualification and Evaluation, proposed a qualitative evaluation system for paleontological heritage, based on its content. This system applies to both fossil assemblages in geosites and fossil collections in museums and similar institutions. Compared to other systems, this open qualitative approach offers significant advantages: it integrates paleontological heritage into a unified geoconservation evaluation methodology, incorporates both sample- and site-based evaluation procedures, and is easily adaptable for assessing other geological objects, such as mineral and rock samples in museums.

Italian law n. 1089 (GU n. 184, 1936) designates fossils as national properties integral to cultural heritage [16]. In Italy, the collection and trade of fossils is illegal, although commerce involving legally certified foreign fossils is permitted. The Code of Law for Cultural Heritage and Landscape (D. L. 22 January 2004, GU ser. Gen. n. 45 24 February 2004—Suppl. Ordinario n. 28) outlines procedures for reporting paleontological discoveries [17]. Activities related to the excavation, study, and promotion of fossils must occur under the supervision of the superintendence [18,19]. Within this regulatory framework, a specialized unit of the Comando Carabinieri, known as the "Nucleo Tutela Patrimonio Culturale" (NTPC), investigates illegal fossil collection and trade. Recently, the Società Paleontologica Italiana (SPI; Italian Paleontological Society) provided the Ministry of Culture with a list of expert paleontologists, often academics, across Italy to assist local superintendencies in the recovery and protection of fossils [18]. Paleontologists are frequently called upon to understand the scientific relevance of a fossiliferous outcrop as well as to ascertain the provenance of confiscated fossil specimens during legal proceedings, and the authenticity of fossils in suspected fraud cases [20]. The taxonomic identification and geographical origin of fossils are essential for these investigations, as they help define the severity of crimes against cultural heritage [20]. The differentiation between common and rare fossils is significant in judicial contexts, indicating whether fossils originate from protected areas or nations with specific regulations. Instances of counterfeit fossils being sold fraudulently are also of interest [20]. Fossil collections in museums and universities serve as reference samples for sworn appraisals during legal cases.

Given Italy's extensive fossiliferous sedimentary outcrops, protecting this heritage presents challenges [17,21–24]. Additionally, many sedimentary formations yield significant fossil finds, necessitating strategic decisions about what to protect for sustainable land use. The involved institutions are interested in methods for distinguishing between common and rare fossils and how to adapt legal frameworks to the diverse fossil record, also from the perspective of the promotion of paleontological heritage. Geosites and geoparks could

effectively safeguard and promote Italian fossils in their natural settings, while museums can give conceptual and didactic contextualization [25,26].

In Calabria, a region of southern Italy, collaboration between institutions has led to significant results in the management of paleontological heritage, both for the fossiliferous areas and for the collections stored in museum and similar institutions.

2. The Paleontological Heritage of Calabria

From a cultural perspective, Calabria is primarily recognized for its rich archeological heritage from the "Magna Graecia" age. However, the region also has a rich natural heritage, preserved in three national parks: Pollino National Park in the north of the region, Sila National Park in the center, and Aspromonte National Park in the south [27]. They have been officially designated as UNESCO Geoparks, highlighting their significant geological heritage. Calabria has a complex geological history, due to its location in the Central Mediterranean. The geological diversity of the region contributes to its unique landscapes and ecosystems. The presence of scientific institutions in the region has facilitated the recovery and preservation of fossils, significantly increasing research and fostering the creation of local museums.

There are two main universities conducting research on the paleontological record of Calabria: the University of Calabria focuses primarily on invertebrates, while the University of Messina, located in the nearby region of Sicily, mainly conducts research on vertebrates. Research is authorized and supervised by superintendence officers in charge of the fossil recovery area. Discoveries and reports of fossils by paleontologists and private citizens must be submitted to the superintendence, which requests a report from experts designated by the Ministry of Culture through the Italian Paleontological Society (SPI). The experts designated for Calabria are two of the authors of this paper: A.G. for invertebrates and A.C.M. for vertebrates. The superintendence and experts are also requested to determine the origin and value of fossils seized by the Comando Carabinieri Nucleo Tutela Patrimonio Culturale of Cosenza (NTPC, a special unit of Carabinieri devoted to the preservation of cultural heritage). The confiscated fossils are studied and stored in laboratories and storerooms authorized by the superintendence.

In Calabria, the preservation and promotion of paleontological heritage is primarily carried out in museums, where fossils are integrated into different exhibition pathways: University Museums, Local Museums, and National Archeological Museums (Table 1). In particular, fossils of marine and terrestrial mammals made significant contributions to understanding the paleogeography and paleoecology of this region, located in the central Mediterranean area. In this paper, we present three different experiences of fossil promotion in three distinct types of museums: a National Archeological Museum (MArRC, Archeological Museum of Reggio Calabria), a University Museum (Paleontology Section of the Museum System of the University of Calabria (SiMU), Rende, Cosenza), and a Civic Museum (MuRi, Museum of Ricadi, Vibo Valentia, VV, Italy).

At MArRC, the exhibition is mainly focused on archeological remains of Magna Graecia, but the museum itinerary is wider, from prehistory to the Roman Age.

SiMU is a University Museum with research and didactic aims, showing the history of life, but also exhibiting local fossils in its Paleontology Section. The museum also stores confiscated fossils coming from the combined actions of the Carabinieri, judicial authorities, and paleontologists.

MuRi is a Civic Museum in the area with different sections devoted to collections ranging from folklore to archeology and paleontology. The paleontological exhibition is devoted to fossil mammals from the upper Miocene outcrops of the inland.

Table 1. Main museums with paleontological exhibitions in Calabria.

Museum	Type	Location
Civic Museum of Longobucco—Section Ammonites	Local Museum	Longobucco, Cosenza
SiMU—Museum System of the University of Calabria	Didactic (history of life) + local fossils in Paleontology Section	Rende, Cosenza
MuRi—Civic Museum of Ricadi	Local Museum	Santa Domenica, Vibo Valentia
MuMe—Civic Museum of Parghelia	Permanent exhibition of local fossils	Parghelia, Vibo Valentia
MuMat—Civic Museum of Tropea	Paleontology Section within the "Sea Museum"	Tropea, Vibo Valentia
Civic Museum of Paleontology and Natural Sciences	History of life and local fossils	Bova, Reggio Calabria
MArRC—Archeological Museum of Reggio Calabria	National Museum—Prehistory Section	Reggio Calabria

3. The National Archeological Museum of Reggio Calabria (MArRC)

MArRC (Museo Archeologico Nazionale di Reggio Calabria) is located in Reggio Calabria, and it is mainly known for housing the famous Bronzi di Riace, two magnificent ancient Greek bronze statues that date back to the 5th century BC. The museum exhibits the rich cultural heritage of Calabria and the wider Mediterranean region. It is housed in a modern building with wide exhibition spaces, where the collections are well lit and well explained. In addition to the Bronzi di Riace, MArRC exhibits huge collections of artifacts from the ancient Greek and Roman periods, pottery, sculptures, and coins, all of which narrate the history of the region. The museum also features educational programs and temporary exhibitions.

As already mentioned, the museum is mainly focused on archeological finds from Magna Graecia, but the exhibition covers a wide span of time, from prehistory to the Roman Age. The Prehistory Section includes tools, pottery, and ornaments from the Paleolithic to the Bronze Age, highlighting the technological advancements and daily life of early inhabitants. The early hunting and gathering practices are evidenced by finely crafted flint tools, while their artistic sense is observable in decorated ceramics. Interactive displays provide context to the artifacts, detailing the environmental conditions and social structures of prehistoric societies. Educational panels invite further exploration of themes such as migration patterns, subsistence strategies, and the significance of ritual practices.

The fossils shown mainly refer to the mammal fauna associated with Neanderthal fossil bones in the sites of Archi (Figure 1a,b) and Nicotera (Figure 1b). The fossils are housed in wide showcases and allow researchers and visitors to reconstruct the environmental conditions about 40,000 years BP.



(**a**) (**b**)

Figure 1. MArRC: (**a**) showcase with fossil mammals associated with *Homo neanderthalensis* from Archi and explanatory panels in the background; (**b**) showcase with *Homo neanderthalensis* and associated artifacts and fossils from Archi and Nicotera. Photos by F.S.

At Contrada Iannì (Nicotera, Vibo Valentia), a fossil mammal assemblage was discovered in coastal plain deposits attributed to the Upper Pleistocene [28]. The mammal assemblage includes *Dama dama* cf. *tiberina*, *Palaeoloxodon* cf. *antiquus*, *Stephanorhinus* sp., *Hippopotamus* sp., *Bos primigenius*, and *Crocuta* sp. [28]. The site yielded a parietal bone fragment from a child of *Homo neanderthalensis* [28]. From the site of Archi, (Reggio Calabria) come *Homo neanderthalensis*, *Palaeoloxodon antiquus*, *Stephanorhinus kirchbergensis*, *Hippopotamus* sp., *Cervus elaphus*, *Megaceros* [recte *Megaloceros*] sp., and *Bos primigenius* [29–31]. Other remains, considered sub-fossils, have been recovered from Grotta del Romito, a cave famous for its burials and prehistoric rock art, particularly a remarkable engraving of an aurochs (*Bos primigenius*), which date back to the Late Pleistocene. The large mammal assemblage comes from levels attributed to the final Epigravettian and includes mainly ibex (*Capra ibex*) and wild boar (*Sus scrofa*), subordinately roe deer (*Capreolus capreolus*), red deer (*Cervus elaphus*), chamois (*Rupicapra* sp.), horse (*Equus ferus*), and aurochs (*Bos primigenius*) [32–35]. Excavations have also revealed nine *Homo sapiens* burials dated to the Late Upper Paleolithic [32,33].

Educational Services

MArRC in Reggio Calabria offers a range of educational services for visitors of all ages and backgrounds, including schools, families, and researchers. The museum offers guided tours in different languages tailored to the specific needs of visiting groups. The exhibition and the educational services are also accessible to people with disabilities. To promote active learning, MArRC organizes workshops through hands-on activities on ancient techniques, artistic expression, and archeological methods. The fossils on display are animal remains found in archeological contexts and are considered in the activities. Moreover, there is constant collaboration with local schools to increase awareness of the cultural heritage of the area. Educational services are complemented by brochures and digital resources.

MArRC hosts temporary exhibitions and lectures by experts ranging from art to literature and from archeology to paleontology. Cultural events provide opportunities to engage a broad audience with new research and reinforce the dialog between the museum and the local community, which consistently demonstrates strong interest and active participation.

4. The Museum System of the University of Calabria (SiMU)

The Museum System of the University of Calabria (SiMU), which includes a Paleontology Section, the Rimuseum—Museum of the Environment, a Botanical Garden, a Zoology Section, a Mineralogy and Petrography Section, and the Archeolab Center, safeguards and preserves an extensive collection of specimens. Its mission is to enhance educational services through innovative approaches. SiMU embraces the challenge of engaging the public in a modern and interactive way, offering educational and informational programs that present its collections, activities, and research in an engaging and participatory manner. The SiMU collections play a crucial role in Third Mission initiatives, where museums act as cultural mediators, fostering the dissemination of scientific knowledge to society.

4.1. Paleontology Section

The Paleontology Section, inaugurated in May 2009, was idealized and realized by Franco Russo and Adelaide Mastandrea, Professors of Paleontology at the Department of Biology, Ecology and Earth Sciences of the University of Calabria. It is located on the top floor of Edifice 14B. It covers approximately 250 m^2 and houses a vast collection of fossilized plants and animals from various locations in Calabria and around the world. The exhibition

is structured as an educational journey through four rooms, allowing visitors to immerse themselves in past life forms while chronologically exploring key evolutionary milestones (Figures 2a–f and 3a–d). These are illustrated through fossils and explanatory panels that provide environmental and geological context. Beginning with the earliest evidence of life (stromatolites), dating back approximately 3.5 billion years, the exhibition guides visitors through geological eras, showcasing the Earth's environmental and biodiversity changes over time.



Figure 2. Exhibition rooms of the Paleontology Section of the Museum System of the University of Calabria (SiMU): (**a**) entrance, showing the architecture and the installation setup; (**b**) Precambrian Room, with exhibitions of the Ediacara fauna and stromatolites; (**c**) Paleozoic Room, showing trilobites as the representative fossils of the Paleozoic Era; (**d**) Mesozoic Room, showing ammonites as the representative invertebrate fossils of the Mesozoic Era; (**e**) panoramic view of the room dedicated to the dinosaurs of the Mesozoic; (**f**) view of the Cenozoic Room, dedicated mainly to the fossiliferous site of Cessaniti with fossils and a paleoenvironmental reconstruction of the site. Photos by A.G.



Figure 3. Paleontology Section of the Museum System of the University of Calabria (SiMU): (**a**) educational activities concerning guided tours and (**b**) paleontological laboratories; (**c**) interactive multimedia systems implemented with multi-touch tables; (**d**) collection of fossils derived from the activities of the Comando Carabinieri Nucleo Tutela Patrimonio Culturale (NTPC). Photos by A.R.

Among the exhibited specimens, local fossils hold significant scientific value, offering visitors insights into the region's paleontological heritage. The fossils, sourced from various locations, depict the gradual evolution of life, which began over 3 billion years ago on an inhospitable planet and experienced dramatic diversification around 541 million years ago. The Paleontology Section aims to provide accurate scientific knowledge about the natural world, particularly the history of life, to foster environmental awareness and critical thinking on territorial issues, and to inspire independent research and study.

4.1.1. Exhibition Rooms

Precambrian Room: The journey begins in the Precambrian Room, where visitors can observe some of the oldest known life forms, dating back approximately 3.5 billion years. These include stromatolites, sedimentary structures formed by the activity of photosynthetic microorganisms, particularly cyanobacteria, and the first preserved pluricellular organisms, the Ediacara fauna (Figure 2b). This last represents a unique assemblage of soft-bodied organisms, preserved worldwide as fossil impressions in sandstone from the Ediacaran

Period (approximately 635 million to 541 million years ago), which marks the final interval of both the Proterozoic Eon (2.5 billion to 541 million years ago) and the Precambrian (4.6 billion to 541 million years ago). Traditionally, this fauna is seen as a significant milestone in the evolution of life on Earth, as they immediately precede the explosion of life forms at the beginning of the Cambrian Period, around 541 million years ago.

Paleozoic Room: In the Paleozoic Room, visitors can explore primitive invertebrates that inhabited ancient seas, such as trilobites (Figure 2c), nautiloids, and crinoids. The exhibition also traces the evolution of fish and the transition of amphibians and reptiles to terrestrial life. A highlight of this section is the skull of *Dunkleosteus*, a massive Devonian predator that could reach up to ten meters in length.

Mesozoic Room: The third exhibition room displays numerous invertebrates, among which a rich ammonite collection (Figure 2d), and fossil vertebrates, including a complete skeleton of the herbivorous dinosaur *Ouranosaurus nigeriensis* [36], a small running dinosaur *Coelophysis*, a flying reptile *Anhanguera* sp., and a cast of "Ciro" (*Scipionyx samniticus*) [37,38], the first Italian fossilized dinosaur with preserved internal organs. Also featured is a skull of *Tyrannosaurus rex*, one of the larger carnivorous dinosaurs (Figure 2e).

Cenozoic Room: The final room is dedicated to fossils discovered in Calabria, primarily Miocene invertebrates and vertebrates from the Cessaniti site (Vibo Valentia) (Figure 2f). Notable specimens include echinoids of the genus *Clypeaster* [39], *Metaxytherium serresii* [40], a marine mammal related to modern dugongs, and *Samotherium* cf. *bossieri* [41], a giraffid genus. The fourth room also houses a rich collection of Late Pleistocene mollusks from Bovetto (Reggio Calabria).

4.1.2. Collections

The collections have expanded through field excavations, acquisitions, and private donations. Additionally, numerous confiscated specimens by the Comando Carabinieri NTPC (Cosenza) have been entrusted to the museum for safekeeping and display, such collections from Vibo Valentia, which hold significant paleontological value at both local and regional levels (Figure 3d). Since 2001, the cataloging of specimens is managed through a dedicated database, compatible with national cataloging projects, which currently includes approximately 40% of the specimens. Although the database structure does not fully align with the "Natural Heritage—Paleontology" cataloging standards set by the Central Institute for Cataloging and Documentation (MiBACT), it allows for seamless integration with ministerial archives.

4.1.3. Educational Services

The Paleontology Section of SiMU is more than just a fossil collection; it is a center for scientific dissemination. Recently, it was enhanced with an interactive multimedia system featuring three multi-touch tables that provide in-depth content on fossilization, trace fossils, and human evolution (Figure 3c). This innovative system offers an immersive educational experience, seamlessly integrating with the museum's collections while also providing a fun and engaging way to explore paleontology through quizzes and interactive activities, making it ideal for educational purposes.

Guided tours are designed to be dynamic and participatory, encouraging visitors to actively seek information, analyze specimens, and draw conclusions, transforming a traditional tour into a "mobile laboratory" (Figure 3a). Additionally, the upper floor of the Paleontology Section features a dedicated space for multimedia and interactive activities, including hands-on educational workshops that facilitate learning through manual and playful activities (Figure 3b). These workshops complement themed guided tours by offering scientific insights into topics such as biodiversity and mass extinctions. The museum

also represents an important educational support for university courses, internships, and Master's degrees. Many students from different degree courses carry out their internships there, and often the scientific topics covered are the subjects of Bachelor's and Master's theses for the degree courses in Geological Sciences, Natural Sciences, and Technologies for the Conservation and Restoration of Cultural Heritage.

4.1.4. Research Activities

The Paleontology Section of SiMU conducts research in Life and Earth Sciences, with a particular focus on the study, protection, and promotion of geosites linked to Calabria's paleontological heritage. For this aspect, the strict collaboration of the Paleontology Section with the Superintendence of Cultural Heritage and the Comando Carabinieri NTCP is particularly fruitful. The consistency and relevance of these collaborations are revealed by scientific studies and related papers [25,42–46] and public exhibitions. Other research includes (1) the interaction between organisms and sedimentary systems through the study of microbial communities and environmental variations; (2) the biogeochemistry of carbonate sediments; and (3) paleoecological reconstructions in time and space through the study of fossil associations.

5. The Civic Museum of Ricadi (MuRi)

The museum comprises a network of five exhibition sites distributed across the province of Vibo Valentia, showcasing collections of archeological artifacts, traditional crafts, and contemporary artworks that illustrate the evolution of Calabrian culture. Visitors can explore exhibitions that emphasize local history, including the region's maritime heritage, agricultural practices, and traditional craftsmanship. MuRi comprises the Sea Museum and the Onion Museum, both located in Capo Vaticano; the Towers Museum at Torre Marrana in Brivadi; the Anthropological and Olive Oil Museum in Ricadi; and the Archeological and Paleontological Museum in Santa Domenica [47]. The total exhibition area covers approximately 1300 m^2, with 200 m^2 allocated to the library. The five museums are housed in historic or traditional buildings, which also feature outdoor spaces.

5.1. Paleontology Section

The Paleontology Section is housed in a historical building in the town of Santa Domenica (Vibo Valentia). The building, originally a manor house, has been completely renovated to house the Archeological and Paleontological Museum, where a 40 m^2 room is occupied by the Paleontology Section and an almost equal room is devoted to archeology. The building also has a well-equipped conference room. The paleontological collections include fossils of the Late Miocene, coming from the Monte Poro-Capo Vaticano area and, in particular, from the key site of Cessaniti (VV) [48]. These fossils include marine vertebrates, such as fish, sharks, and marine mammals, as well as invertebrates, primarily represented by echinoids of the genus *Clypeaster* [39,48]. Among marine mammals, the Sirenian *Metaxytherium serresii* is the most abundant, while Odontocetes (Physiteroidea indet.) and Mysticetes (*Heterocetus* cf. *guiscardii*) are rare [40,49]. A valuable collection of land mammals also comes from Cessaniti and includes *Stegotetrabelodon syrticus*, *Tragoportax* cf. *rugosifrons*, *Ceratotherium advenientis*, *Samotherium boissieri*, *Bohlinia attica*, and an undetermined *Anthracotherid* [40,41,45,46,50–52]. The good preservation of these specimens [25,44] provides valuable insights into ancient marine ecosystems as well as into a land whose geographic location in the Mediterranean basin is still unknown [53]. The exhibition is descriptive of the site, with a focus on mammals. The path starts with the reconstruction of the stratigraphy, with stepped display supports representing the different levels, where the most representative fossils are placed (Figure 4a). A large showcase exhibits the fossils of

Tragoportax cf. *rugosifrons*, *Ceratotherium advenientis*, *Bohlinia attica*, and the undetermined Anthracotherid. Another showcase is devoted to two exceptionally preserved forelimbs of the giraffid *Samotherium boissieri*, discovered in anatomical connection (Figure 4b).



(**a**) (**b**)

Figure 4. MuRi—Archeological and Paleontological Museum: (**a**) stratigraphy of Cessaniti; (**b**) articulated forelimbs of *Samotherium boissieri*. Photo by V.C.

Fossils of *Heterocetus* cf. *guiscardii* (fragmented hemimandible and vertebrae) are dis-played on a large platform, resting on the sediment that originally contained them (Figure 5a). A partial skeleton of *Metaxytherium serresii* is displayed on a support covered with sediments from the site where it was found. A display case with a mirror at the bottom allows visitors to admire two well-preserved *Metaxytherium serresii* skulls, one of which won the Best Regional Fossil 2024 Award organized by the Italian Paleontological Society (Figure 5b). Some display cases house fossils from local collections donated to the museum.



(**a**) (**b**)

Figure 5. MuRi—Archeological and Paleontological Museum: (**a**) fragmented hemimandible and vertebrae of *Heterocetus* cf. *guiscardii*; (**b**) skulls of *Metaxytherium serresii* displayed with a mirror to appreciate the ventral view; the specimen on the right side is the winner of the Best Regional Fossil 2024 Award, organized by the Italian Paleontological Society. Photos by V.C.

5.1.1. Three-Dimensional Analysis and Replicas

The availability of showcases on the external walls of the building was not compatible with the security requirements for fossils. The showcases were set up with 3D-printed replicas of *Clypeaster* sp. (Figure 6), provided by "Air-Innovation" (San Nicolò di Ricadi, VV).



Figure 6. MuRi—Archeological and Paleontological Museum, external showcase: replicas of *Clypeaster* sp. by 3D modeling and printing. Photo by V.C.

Methods

The digital reconstruction of specimens was based on the Structure from Motion (SfM) paradigm, which employs photogrammetric triangulation. A set of images captured from different perspectives was processed to automatically identify points of interest and establish spatial correspondences. These correspondences enabled the creation of a dense point cloud, from which a three-dimensional mesh was subsequently generated. This approach, widely used in geological and archeological contexts, is particularly effective for fossil documentation, ensuring high metric and morphological accuracy.

The obtained digital models were then converted into a format suitable for 3D printing. FDM (Fused Deposition Modeling) technology was chosen for its cost-effectiveness and speed of execution, proving sufficient to reproduce the main macro- and mesoscopic features of *Clypeaster*. In research contexts, such replicas allow for comparative measurements or destructive tests without compromising the original specimens. Additionally, FDM printing facilitates the creation of multiple copies for use in educational or exhibition collections.

The combined application of photogrammetry and FDM has enabled the production of faithful physical replicas in detailed reproduction. The comparison between digital and analog measurements showed an average deviation of less than 1% in the main linear dimensions, confirming the dimensional validity of the method. From an educational perspective, 3D printing provides manageable copies for students or museum audiences, preserving original specimens, which are often rare or fragile.

5.1.2. Educational Services

The educational services include guided tours, which are not regularly scheduled. The majority of visitors are tourists during spring/summer and school groups during autumn/winter. The collaboration with MuMe (Museo della Memoria) at Parghelia (Vibo Valentia), still in progress, is aimed at the realization of an educational–experiential room devoted to paleontology, which will complete the museum network. The museum is fully accessible to visitors with disabilities.

5.1.3. Research Activities

The fossils exhibited in the museum have been included in several studies devoted to the geo-paleontology of the Monte Poro-Capo Vaticano area, in direct collaboration with the Universities of Messina and Calabria, under the supervision of the superintendence in charge. Other national and international institutions have been involved in specialized

studies. Marine mammals from the museum collections have been studied in terms of taxonomy and paleoecology [40]. Land mammals have been studied for their taxonomical assessment as well as for their paleoecological and paleogeographical significance (main papers: [41,45,46,50–52,54]). Some fragmentary specimens are still under study.

6. Discussion

The museums described here offer different perspectives of fossil conceptualization to a wide range of visitors. Every object assumes proper significance within an exhibition, which can be a part of its full scientific/artistic/cultural meaning [10,22].

At MArRC, fossils are strictly related to the prehistoric settlements of *Homo neanderthalensis* and *Homo sapiens*. The large mammals associated with *Homo neanderthalensis* at Archi do not have traces of hunting, and their occurrence in alluvial deposits leads researchers to affirm that their remains were transported during floods. The mandible of a Neanderthal child seems to have been subjected to the same type of transport and accumulation. The mammal assemblage reflects the environmental conditions of the Late Pleistocene in southern Italy, characterized by a temperate climate also during glacial phases. Similar conditions are observed at Nicotera. The large mammal remains from Grotta del Romito, instead, are indicative of hunting and feeding habits of the human populations inhabiting the cave proximities.

The Paleontology Section at SiMU is mainly focused on the history of life, but the showcases devoted to local fossils assume a great relevance, highlighting the presence of the university in the area and its collaborations with other institutions. The section is devoted to university and school students as well as to more generalist visitors, guided through the major evolutionary steps of life on Earth by the fossils, descriptive panels, and interactive resources. The local fossils are useful not only to reconstruct the geo-paleontology of the region of Calabria, but also to raise awareness of their protection.

The museal network of Ricadi is focused on territorial peculiarities, from cultural, anthropological, and naturalistic points of view. The paleontological exhibition exclusively includes Late Miocene fossils from the Monte Poro-Capo Vaticano area. The large mammals show affinities with the Greco-Iranian ones, suggesting intriguing applications in paleogeography. New advances in research have prompted the re-organization of the educational services and new projects are in progress.

In these three contexts, the collaboration among the institutions involved is important. Except for MArRC, which is a National Archeological Museum following a specific procedure, the paleontological museum projects are coordinated and approved by the Superintendence of Cultural Heritage of Calabria, and they are finalized after receiving the necessary permissions from the Italian Ministry of Culture. The paleontological heritage of the three museums comes from acquisitions of private and/or seized collections, recoveries following alerts to authorities, and research activities. The paleontological specimens are usually acquired through several steps: discovery, notification to the authorities, recovery, and preservation. In some cases, they come from private collections, which are not always authorized, and are acquired through amnesty or seizure. It is quite common for fossil specimens to be seized following reports or investigative activities conducted by the special unit of the Carabinieri, NTCP. An important aspect is the accurate taxonomic determination and provenance of fossils, often entrusted to paleontologists from universities, who can indicate whether the fossils originate from a national or international dark market or from field collections in locations within the region. After the investigations and any legal proceedings, the placement of the fossils is decided by the superintendence. The subsequent setup of the museums, as well as their accessibility and maintenance, depends on the availability of the administrations involved and the possibility of funding.

The collaboration between museums, universities, and the superintendence has been particularly beneficial in the three case studies presented here, to the extent that it does not cease at the time of the museum's establishment but continues with ongoing updates from research activities. These initiatives are well suited to the need for scientific dissemination in research, and many European projects have made the dissemination and communication of results mandatory (e.g., Horizon 2020). One of the most effective ways to disseminate research results is to maximize the potential of non-formal contexts [55]. Museums have a strong educational value and, thanks to the results of academic research, can play an effective role within the local community, conveying increasingly novel and captivating messages [56]. This substantial link has also been highlighted by the National Agency for Evaluation of the University and Research System (ANVUR), which in 2013 included the activities of the museum systems of the universities in the Third Mission of the Italian Universities, which includes public engagement activities. This decision pushed universities to take greater account of the activities carried out to disseminate knowledge and to ensure the access of an increasing proportion of citizens to their scientific heritage.

Scientific museums are particularly versatile and prone to publicizing science and promoting new forms of communication and active participation from people of all ages [57]. Science communication helps to reduce the gap between the scientific community and citizens by making scientific notions and information more accessible and encouraging public participation, thus arriving in a situation of dialog and often also understanding and agreement [58,59]. The three museums undertake various initiatives aimed at fostering openness and active engagement with the public, ensuring their participation in the objectives and achievements of university research in the field of paleontology. The outcomes achieved through both inclusive and participatory educational activities not only serve as a valuable resource for academic research and protection initiatives but also function as an effective means of communication with the local community and a vehicle for social inclusion. The museums have welcomed numerous educational institutions, both Italian and international, as well as organized groups.

MArRC welcomes a large number of visitors thanks to the strong appeal of the Bronzes of Riace and its rich collections. The museum is visited by school groups from all over Italy, as well as by tourists organized in family units or groups, including cruise passengers. The museum is also attractive to the residents of Reggio Calabria and nearby cities, due to the intense cultural activities conducted even outside of peak tourist seasons.

Since its foundation in 2009, the Paleontology Section of SiMU has been dedicated to knowledge dissemination and education, with a continuous expansion of its efforts in these areas. The museum has welcomed numerous educational institutions, both Italian and international, as well as organized groups. School groups, in particular, make up the largest segment of visitors, engaging in specialized educational activities through multimedia presentations and interactive workshops. These activities, which often include hands-on learning experiences, immerse students in the topics being studied, enhance their understanding, and make scientific subjects more engaging and accessible.

The Paleontological Section of MuRi has a high number of visitors, primarily family groups, during the tourist season, given its location on a very beautiful coastline, rich in holiday homes and resorts. During the winter months, however, the main visitors are school groups.

The three museums also play a role in raising public awareness about the importance of preserving and enhancing fossils in institutional sites, where they become common goods accessible to all. Through educational initiatives, visitors understand that clandestine private collections deprive the community of knowledge and sense of identity.

The Paleontology Section of SiMU-Unical also has a crucial role in the conservation and promotion of fossil specimens discovered in the Calabria region, particularly those from the Cessaniti (VV) area. An agreement is being formalized that will strengthen joint actions with the University of Messina and MuRI to foster the protection and promotion of Cessaniti's paleontological heritage. Fossils from Monte Poro-Capo Vaticano, mainly represented at Cessaniti, are an important example of past biodiversity, specifically the ancient Miocene paleoenvironment of Calabria, with significant museological and educational value. Regional fossils hold a notable socio-cultural significance, necessitating their preservation and enhancement to promote awareness of Calabria's unique geological heritage while also addressing issues related to the recovery and conservation of paleontological assets. Moreover, the close collaboration of the SiMU Paleontology Section with the Comando Carabinieri NTCP plays a crucial role in preserving regional's rich paleontological heritage, combining academic expertise with law enforcement efforts to combat theft, illicit trafficking, and the illegal excavation and collection of fossils. Moreover, this collaboration has a pivotal role in expanding the paleontological collection for educational and research purposes, while simultaneously strengthening public outreach initiatives and fostering heightened awareness about the critical importance of safeguarding the region's paleontological heritage.

New frontiers are emerging in the dissemination and research activities related to 3D multimedia technology. The digitization of key paleontological specimens is currently underway to create a multimedia exhibition in Calabria. Utilizing state-of-the-art tools such as laser scanners and photogrammetry, fossils are being transformed into digital objects, opening the way for new scientific and museum applications. Indeed, the adoption of digital methodologies in museum contexts is becoming increasingly widespread across all types of exhibitions. Once digitized, the fossils and their corresponding 3D models allow the application of various advanced study techniques, which can be directly integrated into virtual reality environments [60–64]. In this respect, SiMU is setting up a pilot project (Figure 7a–d) that will involve the Calabrian paleontological museums.

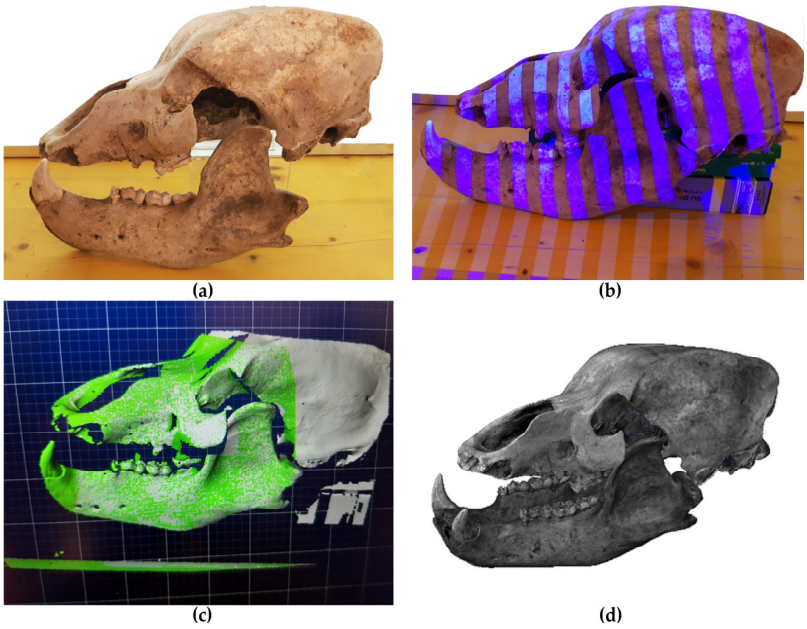


Figure 7. Three-dimensional acquisition of a fossil specimen displayed in the Paleontology Section of SiMU: (**a**) skull of *Ursus spelaeus* subjected to 3D acquisition; (**b**) laser scanner acquisition phase; (**c**) elaboration of the scanned fossil using Structure from Motion (SfM) techniques; (**d**) texture with mesh representing the final reconstruction of the 3D acquisition. Photos by A.G. and A.R.

7. Conclusions

The fruitful collaboration between museums, universities, the judicial system, and the superintendence has created a virtuous circuit which has an impact on tourism, fossil protection, and public awareness initiatives.

The three case studies described here are effective in terms of the promotion of paleontological heritage for the following reasons:

- The three museums offer diverse perspectives on fossils, highlighting paleontological heritage with different approaches and emphasizing its scientific, anthropological, and cultural significance;
- They create a link between research and the public (students and general visitors), using fossils to illustrate the history of life and to enhance or promote the paleontological heritage of the region;
- They make visitors aware of the importance of fossils as cultural heritage and help preserve them from illegal trade and collecting;
- They introduce innovative technologies and digital tools to make the fossil collections more accessible;
- They attract visitors among tourists, helping the tourism industry;
- They involve citizens in cultural initiatives, increasing local community participation.

In conclusion, these case studies from southern Italy demonstrate that a multidisciplinary and cooperative approach is essential for effectively promoting and preserving paleontological heritage. Moreover, the continued commitment of all stakeholders—museums, universities, judicial authorities, and local communities—ensures that paleontological heritage remains a vital and dynamic part of southern Italy's cultural and scientific landscape, and this requires investment in research, conservation, and dissemination activities to ensure that future generations can understand and appreciate this unique legacy.

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Abbreviations

The following abbreviations are used in this manuscript:

MArRC	National Archeological Museum of Reggio Calabria
MIFT	Department of Mathematical, Informatic, Physical and Earth Sciences, University of Messina
MuRi	Museum of Ricadi
SiMU	Museum System of the University of Calabria
VV	Vibo Valentia
NTPC	Comando Carabinieri Nucleo Tutela Patrimonio Culturale

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