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Cover photos by Antonio Calamo (above) and Antonio Croce (below).

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Heterotopic European beech (*Fagus sylvatica* L.) stands on Roccamonfina volcano and adjacent areas (Campania-Latium, central-southern Italy): presence assessment and conservation issues

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Abstract

Heterotopic populations of *Fagus sylvatica* L. occurring outside their ecological *optimum* represent valuable indicators of paleoclimatic continuity and ecological resilience. This study reports and analyzes such beech populations in the Roccamonfina Volcano and adjacent limestone massifs (Monte Maggiore, Monte Cesima, Monte Sammucro) located in Campania and adjacent Latium (central-southern Italy). Through extensive floristic surveys and 20 phytosociological relevés, the study documents the presence, structure, and ecological features of these stands, many of which had not been previously recorded in scientific literature. Multivariate analyses (PCA and Cluster Analysis) reveal floristic patterns shaped by substrate type, elevation, and disturbance regimes. The vegetation is interpreted within the framework of Italian syntaxonomy, with most communities corresponding to Habitat 9210* (Apennine beech forests with *Taxus* and *Ilex*), despite the absence of *Taxus baccata*. Several rare and conservation-relevant species were identified, including native orchids and regionally rare taxa such as *Lilium martagon* and *Acer cappadocicum* subsp. *lobelii*. The study highlights the precarious conservation status of many of these populations, despite their location within protected areas, pointing to inadequate management practices and threats from logging and infrastructure development. These isolated and relict beech stands are of high biogeographic and conservation value and should be prioritized in regional biodiversity strategies.

Keywords: european beech (*Fagus sylvatica* L.), Heterotopic populations, Campania, Latium, Roccamonfina volcano, vegetation, conservation ecology.

Riassunto

Le popolazioni eterotopiche di *Fagus sylvatica* L., presenti al di fuori del loro optimum ecologico, rappresentano importanti indicatori di continuità paleoclimatica e resilienza ecologica. Questo studio documenta e analizza tali popolazioni di faggio sul Vulcano di Roccamonfina e sui massicci carbonatici adiacenti (Monte Maggiore, Monte Cesima, Monte Sammucro), situati in Campania e nel vicino Lazio (Italia centro-meridionale). Attraverso estese indagini floristiche e 20 rilievi fitosociologici, lo studio descrive la presenza, la struttura e le caratteristiche ecologiche di questi popolamenti, molti dei quali non erano stati precedentemente riportati nella letteratura scientifica. Le analisi multivariate (PCA e Cluster Analysis) evidenziano pattern floristici influenzati da tipo di substrato, altitudine e regimi di disturbo. La vegetazione è interpretata secondo la sintassonomia italiana, con la maggior parte delle comunità riferibili all'Habitat prioritario 9210* (Faggete degli Appennini con *Taxus* e *Ilex*), nonostante l'assenza di *Taxus baccata*. Sono state rilevate diverse specie rare o di interesse conservazionistico, tra cui orchidee spontanee e taxa rari a livello regionale come *Lilium martagon* e *Acer cappadocicum* subsp. *lobelii*. Lo studio evidenzia lo stato di conservazione critico di molte di queste popolazioni, nonostante si trovino all'interno di aree protette, a causa di pratiche gestionali inadeguate e minacce legate a tagli forestali e opere infrastrutturali. Questi nuclei isolati e relitti di faggio rivestono un elevato valore biogeografico e conservazionistico, e dovrebbero essere prioritariamente inclusi nelle strategie regionali per la tutela della biodiversità.

Parole chiave: faggio (*Fagus sylvatica*), Popolamento eterotopico, Campania, Lazio, Vulcano di Roccamonfina, vegetazione, Ecologia della conservazione.

Introduction

European beech (*Fagus sylvatica* L.) is distributed across a wide range of Europe, extending from northern Spain to the Black Sea, and from Sicily to the southern regions of the Scandinavian Peninsula (Euforgen, 2009). In Italy, it is native and widespread in all regions, with the sole exception of Sardinia, where it is not indigenous (Bartolucci et al., 2024). Along the Apennine range, its optimal altitudinal distribution typically lies between 1000 and 1700 (occasionally up to 1900) meters above sea level (Pignatti, 1982, 1998).
In Campania, beech forests are present from the northern to the southern sections of the Apennines and other mountainous areas. According to the vegetation series map of Italy (Filesi et al., 2010), in northern Campania and adjacent areas of Latium, these forests are found above 1000 m a.s.l., particularly on the Matese Massif, and potentially in several isolated patches on mountain summits where suitable environmental conditions persist.
From a phytosociological perspective, and following the classification proposed in the *Prodromo della vegetazione d'Italia* (Biondi & Blasi, 2013; Biondi et al., 2014), the beech woods of southern Italy fall within the class *Querco roboris-Fagetea sylvaticae* Br.-Bl. & Vlieger in Vlieger 1937, and belong to the order *Fagetalia sylvaticae* Pawlowski in Pawlowski, Sokolowski & Wallisch 1928. The thermophilous beech forests of the southern Apennines are further classified under the suballiance *Doronico orientalis-Fagenion sylvaticae*.
Heterotopic or extrazonal beech populations are communities that persist in localized microclimatic niches, where conditions remain favorable for their survival despite being outside their optimal climatic zone. These microhabitats provide sufficient moisture and temperature stability, enabling *Fagus sylvatica* to thrive even in areas where the broader phytoclimatic context is less suitable (Pignatti,

1995). Such populations are considered relicts of past paleoclimatic and paleogeographic conditions (Magri, 2008), and their presence is of considerable biogeographical and conservation interest. These relictual heterotopic stands are typically situated outside the main vegetation series to which the species would normally belong.

Several examples of such heterotopic or "depressed" beech populations have been documented across various Italian regions and have been particularly studied in Tuscany and Latium (Roma-Marzio et al., 2017). In Campania, however, the topic has received limited attention, with the only specific study being that of Agostini (1971), who described some degraded populations in the Picentini Mountains. The subject has since been only briefly mentioned, without in-depth treatment, by Saracino (2012).

During floristic surveys conducted in the northern part of the Campania region, we repeatedly encountered populations of *Fagus sylvatica* in areas where its presence had either not been previously recorded or where available information was scant or outdated. For the Roccamonfina volcano, the earliest bibliographic reference to *Fagus sylvatica* is found in the flora compiled by Croce et al. (2008). In the other surrounding territories these plant communities are reported in technical documents recently published by the Campania region, without any reference to their particular interest. With regard to the stands in Latium territory, no prior documentation was found, and thus the data presented in this paper represent new and previously unpublished records.

The most representative beech nuclei discovered during these surveys have been investigated through phytosociological analysis, with the aim of characterizing their vegetation types, assessing their floristic diversity both quantitatively and qualitatively, and highlighting their significance within the broader context of the region's biodiversity.

Materials and methods

For the purposes of this study, we focused on the northern part of the Campania region and the adjacent areas of Latium—territories characterized by relatively limited floristic data (Strumia et al., 2005), and even more deficient with regard to vegetation studies (Filesi et al., 2010). Within this area, heterotopic beech forest stands were identified on the Roccamonfina Volcano, in the Trebulani Mountains (specifically on Mount Maggiore), on Mount Cesima (all located in the province of Caserta, Campania), and on the northern slopes of Mount Sammucro in Latium, together with several isolated individuals (Fig. 1).

The Roccamonfina Volcano is a Late Pleistocene stratovolcano, whose volcanic activity began approximately 630,000 years ago (De Rita et al., 1997). It features a large summit caldera containing two central domes, with Monte Santa Croce reaching 1005 meters a.s.l. The volcanic complex also includes several secondary extracaldera centers, primarily situated in the southern and eastern sectors. The landscape is predominantly covered by chestnut woodlands—both coppices and cultivated orchards—which extend from the lower slopes to the summit.

The volcanic structure is bordered by tectonic depressions and Mesozoic limestone massifs. Among these are Mount Sammucro, Mount Cesima, and Mount Maggiore, aligned in a northwest–southeast direction and running parallel to the Apennine chain. The highest elevations in these massifs are: Mount Sammucro (1205 m), which marks the regional boundary between Latium, Molise, and Campania; Mount Cesima (1180 m); and Pizzo San Salvatore (1037 m).

During our floristic surveys (Croce et al., 2008 and unpublished data), the presence of isolated beech trees as well as actual beech forest stands was georeferenced. Phytosociological sampling was then carried out in areas where *Fagus sylvatica* formed well-structured stands

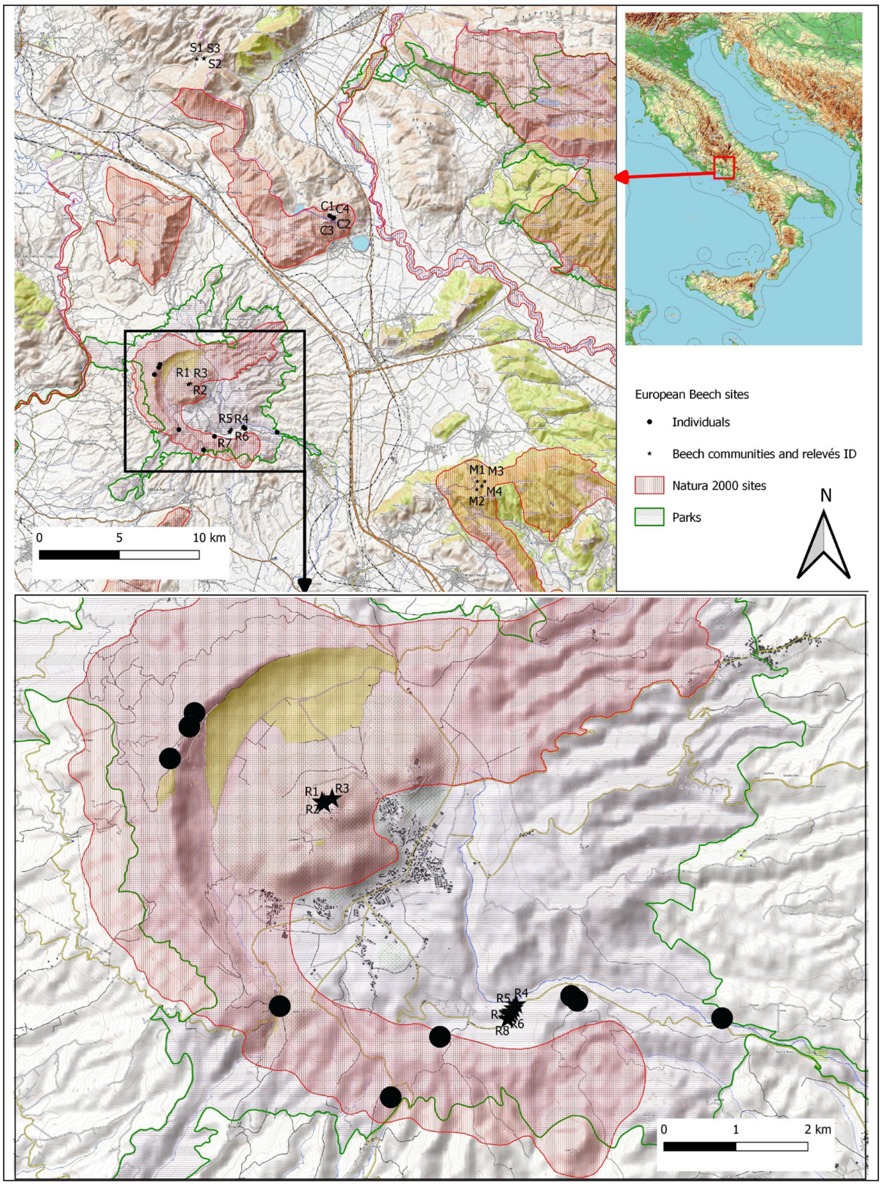

Figure 1: Localization of the sites with *Fagus sylvatica* L. Dots = single individuals, stars = populations and related vegetation relevés.

and possibly reached dominance within the forest canopy (Tab. 1).

A Braun-Blanquet-derived cover-abundance scale was used for vegetation analysis, with the following values:

+ : species present with few individuals and cover <1%
1 : cover between 1–5%
2a : cover between 5–12%
2b : cover between 12–25%
3 : cover between 25–50%
4 : cover between 50–75%
5 : cover between 75–100%

Species recorded only once in the relevés (sporadic taxa) were excluded from the statistical analysis.

The resulting data matrix, was subjected to multivariate analysis. A Principal Component Analysis (PCA) was used to explore patterns of species distribution, and a Cluster Analysis was performed to classify vegetation types. Both analyses were conducted using the PAST software package (Hammer et al., 2001).

Taxonomic nomenclature follows the *Portal to the Flora of Italy* (2024), while syntaxonomic references (Tab. 2) adhere to the *Prodromo della vegetazione d'Italia* (Biondi et al., 2014).

Table 1: Location and site characheristics of the 20 phytosociological relevés in *Fagus sylvatica* stands.

Relevè ID	Locality	Date	Elevation (m a.s.l.)	Aspect (°)	Slope (°)	Surface (m²)	Tot. Cover (%)	Tree cover (%)	shrub cover %	Herb cover (%)	Geological substrate	litter %	UTMx	UTMy	Management	Species richness
R1	M. S. Croce, Roccamonfina Volcano	08/07/2009	845	25	20	100	95	90	15	40	Latite	90	413704	4572315	Young chestnut coppice	30
R2		08/07/2009	870	330	30	80	95	90	60	30	Latite	70	413727	4572297	chestnut coppice	22
R3		08/07/2009	990	275	40	100	100	90	50	25	Latite	90	414045	4572360	chestnut coppice	31
R4	Savone delle Ferriere (Torano), Roccamonfina Volcano	25/06/2009	425	285	50	150	100	95	60	25	Tuffs	95	416400	4569500	chestnut coppice	53
R5		28/06/2012	420	300	60	150	100	90	40	60	Tuffs	95	416365	4569446	old chestnut coppice	56
R6		28/06/2012	420	300	60	150	100	90	30	60	Tuffs	90	416341	4569398	old chestnut coppice	46
R7		28/06/2012	420	300	60	150	100	90	40	30	Tuffs	80	416306	4569366	old chestnut coppice	45
R8		28/06/2012	420	300	60	150	100	100	30	30	Tuffs	90	416283	4569302	beech forest	34
C1	Piano, M. Cesima massif	28/06/2011	665	45	40	150	100	90	80	30	Limestones	95	422750	4582715	beech forest	47
C2		28/06/2011	665	45	30	100	100	90	70	20	Limestones	95	422728	4582658	beech forest	42
C3		28/06/2011	680	45	30	150	100	95	60	50	Limestones	60	422707	4582645	beech forest	28
C4		28/06/2011	715	45	40	150	100	90	70	50	Limestones	90	422730	4582616	beech forest	35
C5		28/06/2011	645	0	40	100	100	95	50	20	Limestones	90	422613	4582809	beech forest	35
S1	Radicosa, M. Sammucro massif	09/07/2011	525	10	60	120	100	95	0	10	Limestones	50	414233	4592612	beech forest	38
S2		09/07/2011	546	20	60	100	100	90	0	30	Limestones	90	414695	4592654	beech forest	25
S3		09/07/2011	555	350	45	100	100	90	0	50	Limestones	60	414680	4592641	beech forest	32
M1	Fosso della Neve, M. Maggiore massif	18/05/2012	585	230	45	200	100	90	50	90	Limestones	90	431781	4566246	beech forest	32
M2		18/05/2012	730	290	45	200	100	90	20	90	Limestones	90	431748	4565734	beech forest	45
M3		08/06/2012	465	290	30	150	100	95	20	90	Limestones	90	432245	4566237	mixed woodland	40
M4		08/06/2012	570	80	50	150	100	90	10	80	Limestones	90	432066	4565948	beech forest	28

Results

A total of 20 phytosociological relevés were conducted in European beech forest communities, resulting in a data matrix composed of 20 relevés and 111 species (Tab. 3). Of the 154 species recorded, 43 were considered sporadic (i.e., occurring in only one relevé). Species richness per relevé ranged from a minimum of 22 species (R2) to a maximum of 56 species (R5).

Roccamonfina volcano

The presence of *Fagus sylvatica* on the Roccamonfina Volcano, between 320 and 990 meters above sea level, has previously been documented (Croce et al., 2008; Croce, 2024) and cited in a regional review on beech forests of Campania and Basilicata (Saracino, 2012). In particular, beech stands were identified in the gorge of the Savone delle Ferriere stream, between the municipalities of Teano and Roccamonfina. Isolated individuals were also recorded near the village of Chiovari and upstream from the village of Preta, often growing on the grey tuff canyon walls. Notably, young trees were observed within chestnut orchards along the provincial road connecting Teano and Roccamonfina—sites relatively distant from the humid microclimate typical of the gorge.

Beech becomes dominant in forest cover downstream of the village of Torano, with scattered individuals found along the stream branches extending westward and northward up to about 600 meters elevation. Isolated young trees were also found along the road from Roccamonfina to Valogno (at 525 m a.s.l.) and near Ponte i Grottoni (535 m a.s.l.) atop the Rio della Selva fluvial incision. These two localities lie approximately 1.5 km southwest and 2 km west, respectively, from the Torano population, within the municipality of Sessa Aurunca.

At higher elevations, close to the species' ecological optimum, a small beech population was found in a chestnut coppice forest on the summit of Monte Santa Croce, on its N-

NW slope between 950 and 990 m a.s.l. A few mature individuals were also observed along the caldera rim north of Monte La Frascara, at about 900 m a.s.l.

Five phytosociological relevés (R4–R8) were conducted in the Torano beech population, representing different degrees of canopy cover. Three additional relevés (R1–R3) were carried out in the Monte Santa Croce population (Tab. 1).

According to the Vegetation Series Map (Filesi et al., 2005), all these sites fall within the central Tyrrhenian pre-Apennine subacidophilous series of *Quercus cerris*, with *Sorbus domestica*, *S. torminalis*, and *Acer opalus* subsp. *obtusatum* in the tree layer, and shrubby mantles dominated by *Cytisus scoparius*. The latter is present exclusively in the Monte Santa Croce communities, where it represents the initial successional stage following coppice cutting.

All beech populations lie within the boundaries of the Roccamonfina-Foce Garigliano Regional Park, with the exception of the Savone gorge sites, which fall outside the Natura 2000 Special Area of Conservation (SAC) IT8010022 "Vulcano di Roccamonfina".

Monte Maggiore

The beech communities of Monte Maggiore are located between 465 and 730 m a.s.l. in the locality of *Fosso della Neve*, within the municipality of Pietramelara. They occur on NW to NE-facing slopes and are represented by four relevés (M1–M4). These communities fall within the central Tyrrhenian Apennine neutro-basiphilous series of the hop hornbeam (*Melittio melissophylli–Ostryio carpinifoliae* sigmetum), dominated by *Ostrya carpinifolia* and *Carpinus orientalis*. *Cercis siliquastrum*, typically associated with this series, is absent or sporadic in the relevés.

While *Acer cappadocicum* subsp. *lobelii* is frequent in the broader area, it is rare in the sampled sites. In contrast, *Acer opalus* subsp. *obtusatum*, *Castanea sativa*, *Fraxinus ornus*, *Ostrya carpinifolia*, and *Quercus ilex* are frequent in the tree layer. The presence of *Quercus ilex*, albeit with low coverage, underscores the thermophilous nature of these communities, further supported by species such as *Anemone apennina*, *Asparagus acutifolius*, *Rubia peregrina*, *Cyclamen repandum*, *Drymochloa drymeja*, *Ruscus aculeatus* and, even as sporadic species, *Polypodium cambricum*, *Phillyrea latifolia*, *Smilax aspera*. The herbaceous layer is dominated by *Sesleria autumnalis*, a characteristic species of this vegetation series.

All beech stands fall within the SAC IT8010006 "Catena di Monte Maggiore".

Monte Cesima

The small beech community on Monte Cesima is located in Valle Casale area, at the base of the NE slope of Monte San Leonardo, and in Piano di Cesima area, at the base of the N slope of Colle Aruta and Colle Traverso. The site ranges in altitude from 645 to 715 m a.s.l., and is represented by five relevés (C1–C5) carried out in the first locality, where beech reaches higher cover values in the tree layer. It falls within the Adriatic neutro-basiphilous series of *Quercus cerris* and *Quercus pubescens* (*Daphno laureolae–Querco cerridis* sigmetum) as defined by Filesi et al. (2010).

The tree layer is dominated by *Quercus cerris*, with accompanying species including *Ostrya carpinifolia*, *Fraxinus ornus*, *Acer opalus* subsp. *obtusatum*, and *Acer campestre*. The shrub layer is poorly developed, with only *Rubus ulmifolius* and *Crataegus monogyna*, both belonging to *Rhamno-prunetea* communities, being frequent - likely due to historical or ongoing grazing pressure or to the fragmentation of this community. The herbaceous layer is diverse, with *Euphorbia amygdaloides*, *Carex sylvatica*, *Lathyrus venetus*, *Melica uniflora*, *Ruscus aculeatus*, *Viola reichenbachiana*, and the regionally rare *Lilium martagon* being of particular interest. Other frequent species include *Sesleria autumnalis*, *Galium odoratum*, and *Daphne laureola*. This site is

Table 2: Syntaxonomic scheme.

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Cl. QUERCO ROBORIS-FAGETEA SYLVATICAE Br.-Bl. & Vlieger in Vlieger 1937
 └─ Ord. Fagetalia sylvaticae Pawłowski in Pawłowski, Sokołowski & Wallisch 1928
     └─ All. Geranio versicoloris-Fagion sylvaticae Gentile 1970
         └─ Suball. Doronico orientalis-Fagenion sylvaticae
             (Ubaldi, Zanotti, Puppi, Speranza & Corbetta ex Ubaldi 1995)
             stat. nov. Di Pietro, Izco & Blasi 2004
             └─ Ass. Anemono apenninae-Fagetum sylvaticae (Gentile 1970) Brullo 1

    Ord. Quercetalia pubescenti-petraeae Klika 1933
     └─ All. Carpinion orientalis Horvat 1958

Cl. QUERCETEA ILICIS Br.-Bl. in Br.-Bl., Roussine & Nègre 1952
 └─ Ord. Quercetalia ilicis Br.-Bl. ex Molinier 1934

Cl. RHAMNO CATHARTICAE-PRUNETEA SPINOSAE Rivas Goday & Borja ex Tüxen 1962
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included in the SAC IT8010005 "Catena di Monte Cesima".

Monte Sammucro

The beech stand on Monte Sammucro is located on the northern slope along the "Rio di S. Vittore" stream, near the village of Radicosa, in the municipality of San Vittore del Lazio (Latium), at elevations between 520 and 560 m a.s.l. (relevés S1–S3). These communities belong to the pre-Apennine neutro-basiphilous series of *Quercus pubescens* (*Roso sempervirentis–Querco pubescentis* sigmetum).
Fagus sylvatica dominates the canopy, with *Acer obtusatum*, *Fraxinus ornus*, and *Quercus cerris* also present. *Carpinus orientalis* is less frequent. Notably, both *Quercus pubescens* and *Quercus ilex*, characteristic of the series, are absent, reinforcing the mesophilic nature of these stands. The shrub layer is composed of deciduous species such as *Ligustrum vulgare* and *Cornus sanguinea*, with no evergreen elements. Similarly to the M. Cesima Relevès, species of *Quercetea ilicis* are here poorly represented. Grazing appears to play a major role in shaping the vegetation structure, as reflected in a herbaceous layer where *Euphorbia amygdaloides*, *Mercurialis perennis*, *Helleborus foetidus*, and *Sesleria autumnalis* are common.
Only a portion of the beech forests, specifically the lower-elevation section, is included within the protected area Monumento Naturale "Monte Sammucro – Terra di Confine", established in 2021 by Latium administrative Region. In particular, the relevé S1 falls within the boundaries of the protected area, while S2 and S3 fall outside it.

Multivariate analysis

Cluster analysis (Fig. 2) revealed distinct groupings among the relevés, mainly structured along substrate. Communities on volcanic soils (Roccamonfina) form a separate cluster from those on carbonate substrates (Monte Maggiore, Cesima, Sammucro), where species of the thermophilous *Carpinion orientalis* alliance (e.g., *Ostrya carpinifolia*, *Fraxinus ornus*, *Sesleria autumnalis*) are more prevalent.

Within the volcanic sites, *Castanea sativa* is always dominant in the tree layer, except in rel. R8, where it is codominant with *Fagus sylvatica*. The species of the *Geranio–Fagion* alliance (e.g., *Cardamine chelidonia*, *Lamium flexuosum*, *Senecio ovatus* subsp. *stabianus*) are well represented. Monte Santa Croce relevés form a compact group with low floristic richness (22–30 species), while the Savone gorge communities show the highest richness (34–56 species).

Relevés from Monte Maggiore host thermophilous elements of the *Quercetea ilicis* class (*Quercus ilex*, *Ampelodesmos mauritanicus*, *Arisarum vulgare*, *Asparagus acutifolius*), and cluster closely with Monte Sammucro relevés, which lack a shrub layer—likely due to grazing, as observed also on Monte Cesima. This disturbance correlates with lower herbaceous richness in these sites. The patterns described above are confirmed by the Principal Component Analysis of the relevés (Fig. 3). The first principal axis accounts for 32.1% of the total variance and primarily represents the substrate gradient separating the volcanic from the limestone sites. The second axis explains 14.6% of the total variance and is associated with a gradient of disturbance or management, with relevés showing lower shrub layer cover positioned in the lower part of the ordination diagram.

Discussion and conclusion

The floristic composition allows to consider the populations here studied as representative of the Priority Habitat 9210*- *Apennine beech forests with Taxus and Ilex* despite the lack of *Taxus baccata.*

The following detected species are, indeed, typical of this habitat: *Ilex aquifolium*, *Anemone apennina*, *Aremonia agrimonioides*, *Cardamine bulbifera*, *C. chelidonia*, *Euphorbia amygdaloides*, *Galium odoratum*, *Lathyrus venetus*, *Melica uniflora*, *Mycelis muralis*, *Potentilla micrantha*, *Ranunculus lanuginosus*, *Rubus hirtus*, *Sanicula europaea*, *Viola reichembachiana*, *V. riviniana*, *Athyrium filix-femina*.

A group of species are of some conservation issues as the native orchids *Neottia nidus-avis*, *Cephalanthera longifolia*, *C. rubra* and *Arisarum proboscideum, Lilium bulbiferum* and *Lilium martagon*, *Acer cappadocicum* subsp. *lobelii* (Regional Law n. 40/1994) and *Ruscus aculeatus* (Habitat Directive 92/43/EEC, annex V).

The most recent observation taken in the studied sites (spring 2025) highlights the critical conditions of most of them, despite they are included in SAC areas, or in Regional parks. The habitat 9210 is recorded in the Standard Data Forms of SACs IT8010005 and IT8010006, but not in IT8010022. Therefore, no specific conservation measures are planned for the latter site. Conversely, beech forests are reported for the studied areas – although not always correctly located due to the adopted scale – in the Habitat Map of Campania (Bagnaia et al., 2017) for Monte Maggiore, Monte Cesima and for the lower sites on Roccamonfina Volcano, but they were either not detected or not reported in the Habitat Map of Latium (Casella et al., 2008) for the Monte Sammucro site. On Roccamonfina Volcano the community on Mount S. Croce underwent the same fate as the surrounding coppiced chestnut woodland and was subject to clear-cut. Only a few shoots or seedlings less than 2 m high along with a few adult plants growing in a protected spot in an impluvium were visible in the site. The beech in Savone gorge is affected by sporadic cuts and its importance is poor known by administrators. As a result, projects affecting the area often fail to properly consider the impacts on the beech population and the surrounding ecosystem. These observations let us think that although the majority of the communities fall within designated protected zones, their management—often guided by assessments that inadequately consider ecological and conservation criteria—raises significant concerns regarding the long-term effectiveness of habitat (and species) preservation.

Table 3: Phytosociological relevés in *Fagus sylvatica* sites on Roccamonfina Volcano (R), Monte Maggiore (M), Monte Cesima (C), and Monte Sammucro (S).

		R1	R2	R3	R4	R5	R6	R7	R8	C1	C2	C3	C4	C5	S1	S2	S3	M1	M2	M3	M4	Presence	Frequence
	Char. assoc. *Anemono apenninae-fagetum*																						
Paleotemp.	*Melica uniflora* Retz.	1	.	1	2a	1	1	1	1	2a	1	1	+	1	2a	1	.	.	+	+	+	17	V
Pontico	*Lathyrus venetus* (Mill.) Wohlf.	.	.	+	+	.	.	.	.	2a	1	1	1	1	+	.	1	1	+	+	+	13	IV
Submedit.-Subatl.	*Ilex aquifolium* L.	+	.	.	2a	1	.	1	1	.	.	2a	2b	2b	.	.	+	.	2a	+	.	11	III
C-Europ.Caucas.	*Euphorbia amygdaloides* L. subsp. amygdaloides	.	.	.	.	.	.	.	.	1	+	+	+	+	1	+	+	.	.	.	.	8	II
Euri-Medit.	*Potentilla micrantha* Ramond ex DC.	.	.	+	+	+	.	.	.	2a	1	.	+	+	.	.	.	.	.	+	.	8	II
SE-Europ.	*Anemone apennina* L.	.	.	.	.	.	.	.	.	.	+	.	+	.	.	.	.	2a	+	+	.	5	II
	Char. all. *Geranio versicoloris-Fagion*																						
Submedit.-Subatl.	*Daphne laureola* L.	.	.	.	.	+	+	+	+	1	+	+	1	.	.	.	+	+	+	+	+	13	IV
NW-Medit.	*Lamium flexuosum* Ten. subsp. *flexuosum*	.	.	.	2a	+	2a	1	1	.	.	.	.	.	.	.	.	.	.	+	+	7	II
Medit.-Turan.	*Drymochloa drymeja* (Mert. & W.D.J.Koch) Holub	2b	2a	.	.	.	.	.	.	.	.	.	.	.	.	.	.	2a	2a	4	3	6	II
Subendem.	*Cardamine chelidonia* L.	.	.	.	1	.	+	1	.	.	.	.	.	.	.	.	.	.	.	+	.	4	I
Steno-Medit.-Occid.	*Allium pendulinum* Ten.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	+	.	+	.	3	I
Orof. NE-Medit.	*Aremonia agrimonoides* (L.) DC. subsp. *agrimonoides*	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	+	+	.	3	I
Endem.	*Senecio ovatus (G.Gaertn., B.Mey. & Scherb.) Willd. subsp. stabianus (Lacaita) Greuter*	+	.	+	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	3	I
Eurasiat.	*Polygonatum multiflorum* (L.) All.	+	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	2	I
Endem.	*Acer cappadocicum* Gled. subsp. *lobelii* (Ten.) A.E.Murray	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	2a	1	I
	Char. ord. *Fagetalia*																						
Centroeurop.	*Fagus sylvatica* L.	2a	4	1	2a	4	4	2a	5	4	4	3	5	5	4	4	5	5	5	4	3	20	V
Eurosiber.	*Viola reichenbachiana* Jord. ex Boreau	.	.	.	.	+	.	+	+	+	+	+	+	1	+	.	+	1	+	1	+	14	IV
Europ.-Caucas.	*Mycelis muralis* (L.) Dumort. subsp. *muralis*	+	.	+	+	1	+	1	+	+	+	.	.	+	1	.	.	.	.	+	.	12	III
Europ.-Caucas.	*Mercurialis perennis* L.	.	.	.	.	.	.	.	.	+	+	2a	1	.	1	2a	2a	.	1	+	+	10	III
Circumbor.	*Polystichum setiferum* (Forssk.) T.Moore ex Woyn.	.	.	.	2a	2a	1	2a	2a	.	.	.	.	.	.	.	.	.	+	2a	.	7	II
Eurasiat.	*Galium odoratum* (L.) Scop.	.	.	1	.	.	.	.	.	1	1	2a	.	+	.	.	.	.	.	1	.	6	II
Subcosmop.	*Geranium robertianum* L.	.	.	2a	.	.	.	+	.	.	+	+	1	.	+	.	.	.	.	.	.	6	II
Eurasiat.	*Carex sylvatica* Huds.	.	.	.	.	.	.	.	.	2a	1	1	1	+	.	.	.	.	.	.	.	5	II
Orof. Eurasiat.	*Salvia glutinosa* L.	.	.	.	2a	+	1	1	.	.	.	.	.	.	+	.	.	.	.	.	.	5	II
Paleotemp.	*Sanicula europaea* L.	.	.	.	+	.	.	.	.	1	.	.	.	+	+	.	.	.	.	+	.	5	II
Eurasiat.	*Neottia nidus-avis* (L.) Rich.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	+	.	+	.	+	4	I
W-Medit.	*Arisarum proboscideum* (L.) Savi	.	.	.	1	.	.	+	.	.	.	+	.	.	.	.	.	.	.	.	.	3	I
Eurasiat.	*Cephalanthera longifolia* (L.) Fritsch	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	+	+	.	.	3	I
Eurasiat.	*Moehringia trinervia* (L.) Clairv.	.	.	+	+	.	.	+	+	.	.	.	.	.	.	.	.	.	.	.	.	3	I

Pontico-C-Europ.	*Cardamine bulbifera* (L.) Crantz	.	.	.	1	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	2	I
Eurasiat.	*Cephalanthera rubra* (L.) Rich.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	+	.	.	.	.	2	I
Orof. SE-Europ.	*Luzula sylvatica* (Huds.) Gaudin subsp. *sylvatica*	.	.	.	.	.	.	.	.	.	.	.	.	2b	.	.	.	.	1	.	.	2	I
	Char. All. Carpinion orientalis																						
SE-Europ.	*Sesleria autumnalis* (Scop.) F.W.Schultz	.	.	.	.	.	.	.	.	2b	.	+	1	3	2a	1	3	3	4	.	4	10	III
Circumbor.	*Ostrya carpinifolia* Scop.	.	.	.	.	.	.	.	.	3	3	.	2b	2a	.	+	.	.	2a	3	2b	8	II
Europ.-Caucas.	*Carpinus orientalis* Mill. subsp. *orientalis*	*2a*	.	.	*2a*	.	.	.	.	.	*1*	.	.	.	*3*	.	*1*	*+*	*1*	.	.	7	II
S-Europ.	*Pseudoturritis turrita* (L.) Al-Shehbaz	.	.	+	+	+	.	.	+	.	.	.	.	.	.	.	.	.	+	.	.	5	II
NE-Medit.	*Melittis melissophyllum* L. subsp. *albida* (Guss.) P.W.Ball	.	.	2b	.	.	.	.	.	.	.	.	+	.	.	+	+	.	.	.	.	4	I
S-Europ.	*Staphylea pinnata* L.	.	.	.	.	2b	.	+	.	.	.	.	.	.	.	.	.	.	.	.	+	3	I
	Char. ord. *Quercetalia pubescenti-petraeae*																						
Euri-Medit.	*Ruscus aculeatus* L.	.	.	.	3	2a	2a	2b	2a	+	1	+	+	1	+	1	+	3	1	2a	1	17	V
Euri-N-Medit.-Pontico	*Fraxinus ornus* L. subsp. *ornus*	.	.	.	.	.	1	.	.	2b	.	+	2b	1	+	2a	2a	2b	2b	+	2b	12	III
Steno-Medit.	*Viola alba* Besser subsp. *dehnhardtii* (Ten.) W.Becker	1	.	.	1	.	.	.	.	1	+	.	+	.	.	+	1	1	1	.	+	10	III
Subatl.	*Helleborus foetidus* L. subsp. *foetidus*	.	.	.	.	.	.	.	.	+	+	+	.	+	+	+	+	.	+	+	.	9	III
Europeo-Pontico	Quercus pubescens Willd. subsp. pubescens	.	.	.	1	+	+	+	+	.	.	.	.	.	.	.	.	.	.	.	.	5	II
Eurasiat.	*Lilium martagon* L.	.	.	.	.	.	.	.	.	+	1	1	1	1	.	.	.	.	.	.	.	5	II
Endem.	*Digitalis micrantha* Roth ex Schweigg.	+	.	.	.	+	+	+	+	.	.	.	.	.	.	.	.	.	.	.	.	5	II
SE-Europ.-Pontico	*Cornus mas* L.	.	.	.	.	.	.	.	.	2a	.	.	1	.	.	.	.	.	2a	.	1	4	I
Subendem.	*Teucrium siculum* (Raf.) Guss.	+	.	.	.	+	+	.	.	.	.	.	.	.	.	.	.	.	+	.	.	4	I
Pontico-SE-Europ.	*Mespilus germanica* L.	.	.	.	.	+	+	+	.	.	.	.	.	.	.	.	.	.	.	.	.	3	0,15
SE-Europ.-Caucas.	*Sorbus torminalis* (L.) Crantz	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	1	.	.	.	2	I
	Char. cl. *Querco-Fagetea*																						
Submedit.-Subatl.	*Hedera helix* L. subsp. *helix*	2a	+	2b	2a	2b	3	2b	2a	3	3	2b	3	4	2b	1	.	2a	2b	3	1	19	V
SE-Europ.	*Acer opalus* Mill. subsp. *obtusatum* (Waldst. & Kit. ex Willd.) Gams	.	.	2b	2a	1	2a	1	.	3	3	4	2b	.	2b	3	3	3	3	1	2b	16	IV
Europ.-Caucas.	*Ajuga reptans* L.	+	.	.	+	+	+	.	+	1	+	.	+	+	1	.	+	+	+	+	+	15	IV
SE-Europ.	*Castanea sativa* Mill.	5	5	5	5	5	5	5	5	.	.	.	.	.	+	.	.	+	+	+	2a	13	IV
Europ.-Caucas.	*Hieracium racemosum* Waldst. & Kit. ex Willd. subsp. *crinitum* (Sm.) Rouy	2a	2a	+	+	+	.	.	.	1	.	.	1	1	+	+	+	.	+	.	.	12	III
SE-Europ.-Pontico	*Lonicera caprifolium* L.	.	.	.	2a	3	2a	1	2a	2a	1	2a	1	1	+	.	.	.	1	.	.	12	III
Euri-Medit.-Sett.	*Quercus cerris* L.	.	.	.	+	+	.	.	.	3	+	3	1	2a	1	+	+	+	.	.	.	11	III
Euri-Medit.	*Luzula forsteri* (Sm.) DC.	1	+	.	+	+	+	+	+	1	1	.	.	+	.	.	.	.	.	.	.	10	III
Europ.-Caucas.	*Acer campestre* L.	.	.	.	+	1	.	+	.	2a	2a	+	.	1	2b	.	.	+	.	.	.	9	III
Paleotemp.	*Campanula trachelium* L. subsp. *trachelium*	+	.	.	+	+	1	.	+	.	.	.	+	+	+	.	+	.	.	.	.	9	III

Europ.-Caucas.	*Festuca heterophylla* Lam.	+	+	+	+	1	+	+	.	.	.	.	1	1	.	.	.	.	.	.	.	9	III
Centroeurop.	*Rubus hirtus* Waldst. & Kit. group	+	+	1	1	2a	1	2b	2a	.	.	.	.	.	.	.	.	.	1	.	.	9	III
Europ.-Caucas.	*Corylus avellana* L.	1	.	4	2b	.	+	1	1	.	.	.	.	.	.	.	.	.	.	+	.	7	II
Eurasiat.	*Euonymus europaeus* L.	.	.	.	1	1	1	+	.	2a	.	.	.	.	.	.	.	+	1	.	.	7	II
Orof. Centroeurop.	*Lilium bulbiferum* L.	.	.	.	+	.	+	.	.	+	.	.	.	.	.	+	+	+	+	.	.	7	II
Circumbor.	*Geum urbanum* L.	.	.	.	.	+	.	+	.	+	+	.	.	.	+	.	.	.	.	+	.	6	II
Submedit.-Subatl.	*Rosa arvensis* Huds.	.	.	.	.	.	.	.	.	2a	1	.	.	1	+	.	+	+	.	.	.	6	II
Eurosiber.	*Solidago virgaurea* L. subsp. *virgaurea*	1	1	.	+	+	.	.	+	.	.	.	.	.	.	.	.	.	+	.	.	6	II
Cosmop.	*Fragaria vesca* L. subsp. *vesca*	1	+	.	.	.	.	.	.	1	.	.	.	.	.	.	.	+	+	.	.	5	II
Euri-Medit.	*Silene italica* (L.) Pers. subsp. *italica*	.	+	.	.	+	+	.	.	1	.	+	.	.	.	.	.	.	.	.	.	5	II
Medit.Atl.(Steno-)	*Clinopodium menthifolium* (Host) Merino subsp. *menthifolium*	.	.	.	.	+	+	.	+	.	.	.	.	.	.	+	.	.	.	.	.	4	I
Orof. S-Europ.	*Laburnum anagyroides* Medik. subsp. *anagyroides*	.	.	.	.	.	.	.	.	.	.	.	4	.	.	+	+	.	.	.	.	3	0,15
Europ.-Caucas.	*Primula vulgaris* Huds. subsp. *vulgaris*	.	.	.	+	+	+	+	.	.	.	.	.	.	.	.	.	.	.	.	.	4	I
Europ.-Caucas.	*Prunus avium* (L.) L.	.	.	.	+	.	+	1	1	.	.	.	.	.	.	.	.	.	.	.	.	4	I
Paleotemp.	*Brachypodium sylvaticum* (Huds.) P.Beauv. subsp. *sylvaticum*	.	+	.	.	.	.	.	.	.	.	.	.	.	2a	.	+	.	.	.	.	3	I
Medit.-Mont.	*Crepis leontodontoides* All.	.	.	.	.	.	.	.	.	1	+	.	+	.	.	.	.	.	.	.	.	3	I
Europ.-Caucas.	*Carpinus betulus* L.	+	.	3	.	.	2a	.	.	.	.	.	.	.	.	.	.	.	.	.	.	3	I
Euri-Medit.	*Sorbus domestica* L.	1	+	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	3	I
Orof. Eurasiat.	*Veronica officinalis* L.	1	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	2	I
	Char. cl. *Quercetea* and ord. *Quercetalia-iliciis*																						
Medit.-Macarones.	*Asplenium onopteris* L.	.	.	+	1	1	+	+	1	+	+	+	.	.	.	.	.	+	1	+	+	13	IV
Steno-Medit.	*Asparagus acutifolius* L.	.	.	.	.	.	.	+	.	.	.	.	.	.	+	+	.	1	.	.	.	4	I
N-Medit.	*Cyclamen repandum* Sm. subsp. *repandum*	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	+	+	+	4	I
Steno-Medit.	*Quercus ilex* L.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	+	.	1	3	I
Medit.-Macarones.	*Rubia peregrina* L.	.	.	.	+	.	.	.	+	.	.	.	.	.	.	.	.	2a	.	.	.	3	I
Steno-Medit.-Sudoccid.	*Ampelodesmos mauritanicus* (Poir.) T.Durand & Schinz	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	+	.	.	.	.	2	I
Steno-Medit.	*Arisarum vulgare* O.Targ.Tozz. subsp. *vulgare*	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	+	.	2	I
	Char. cl. *Rhamno-Prunetea*																						
Euri-Medit.	*Dioscorea communis* (L.) Caddick & Wilkin	.	.	+	2a	1	+	1	+	.	.	.	.	.	+	1	2a	.	.	+	+	11	III
Euri-Medit.	*Rubus ulmifolius* Schott	.	.	.	.	.	.	.	.	4	4	3	3	3	1	.	.	+	.	+	+	9	III
Paleotemp.	*Crataegus monogyna* Jacq.	.	.	.	.	1	1	1	.	3	2b	+	.	1	+	.	.	.	.	.	.	8	II
SE-Europ.	*Cornus sanguinea* L. subsp. *hungarica* (Kárpáti) Soó	.	.	.	2b	1	1	1	1	.	2b	.	.	.	+	.	+	.	.	.	.	8	II
Eurasiat.	*Ligustrum vulgare* L.	.	.	.	+	+	+	+	+	.	.	.	.	.	1	.	.	.	.	.	.	6	II
Europ.-Caucas.	*Clematis vitalba* L.	.	.	.	.	.	.	.	.	1	1	.	+	.	.	+	.	.	+	.	.	5	II
	Other species																						
Cosmop.	*Pteridium aquilinum* (L.) Kuhn subsp. *aquilinum*	+	+	.	.	+	+	+	+	.	.	+	.	2b	.	+	2a	.	.	.	.	10	III

Cosmop.	*Asplenium trichomanes* L.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	+	+	+	.	4	I
Eurasiat.	*Cardamine impatiens* L. subsp. *impatiens*	.	.	.	1	+	+	+	.	.	.	.	.	.	.	.	.	.	.	.	.	4	I
Eurasiat.	*Cruciata glabra* (L.) C.Bauhin ex Opiz	.	.	.	+	+	.	.	.	.	.	.	.	.	+	.	+	.	.	.	.	4	I
Euri-Medit.-Subatl.	*Dryopteris pseudomas* (Woll.) Holub & Pouzar subsp. *pseudomas*	.	.	.	1	+	+	2a	.	.	.	.	.	.	.	.	.	.	.	.	.	4	I
Europ.-Caucas.	*Hypericum montanum* L.	.	.	.	+	+	+	.	.	+	.	.	.	.	.	.	.	.	.	.	.	4	I
Endem.	*Linaria purpurea* (L.) Mill.	.	.	.	+	+	1	+	.	.	.	.	.	.	.	.	.	.	.	.	.	4	I
Medit.-Atl.(Euri-)	*Polypodium interjectum* Shivas	.	.	1	+	.	.	.	.	.	.	.	.	.	.	.	.	+	1	.	.	4	I
Cosmop.	*Stellaria media* (L.) Vill.	.	.	+	.	+	1	.	.	.	.	.	.	.	.	.	.	.	.	+	.	4	I
Paleotemp.	*Dactylis glomerata* L. subsp. *glomerata*	.	.	.	.	.	.	.	.	+	.	.	+	+	.	.	.	.	.	.	.	3	I
Paleotrop.	*Hypericum perforatum* L. subsp. *perforatum*	.	.	.	.	+	.	.	.	+	.	.	.	+	.	.	.	.	.	.	.	3	I
Circumbor.	*Prunella vulgaris* L. subsp. *vulgaris*	.	.	.	.	+	.	.	.	+	+	.	.	.	.	.	.	.	.	.	.	3	I
Submedit.-Subatl.	*Sedum cepaea* L.	.	.	.	.	+	.	.	+	+	.	.	.	.	.	.	.	.	.	.	.	3	I
Europ.	*Viola riviniana* Rchb.	1	+	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	3	I
Steno-Medit.	*Arum italicum* Mill. subsp. *italicum*	.	.	.	.	.	.	+	.	.	+	.	.	.	.	.	.	.	.	.	.	2	I
Europ.-Sudsiber.	*Astragalus glycyphyllos* L.	.	.	.	.	.	.	.	.	+	.	.	+	.	.	.	.	.	.	.	.	2	I
Eurasiat.	*Centaurium erythraea* Rafn subsp. *erythraea*	.	.	.	.	+	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	2	I
Europ.-Caucas.	*Emerus major* Mill. subsp. *major*	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	+	2	I
Europ.	*Cytisus scoparius* (L.) Link subsp. *scoparius*	1	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	2	I
Orof. S-Europ.	Laburnum alpinum (Mill.) Bercht. & J.Presl	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	2a	.	+	2	I

Occasional species

Ril. R1 *Agrotis* capillaris L. +, *Poa nemoralis* L. +; **Ril. R2** *Aira elegans* Willd. subsp. *elegans* +, *Antoxanthum odoratum* L. +, *Erica arborea* L. +, *Polypodium vulgare* L. 1, *Rosa canina* L. +; **Ril. R3** *Aristolochia pallida* Willd. +, *Asperula taurina* L. subsp. *taurina* +, *Cardamine hirsuta* L. +, *Rabelera holostea* (L.) M.T.Sharples & E.A.Tripp +, *Symphytum tuberosum* L. subsp. *angustifolium* (A.Kern.) Nyman +, *Vinca major* L. subsp. *major* +; **Ril. FS1** *Athyrium filix-femina* (L.) Roth 1, *Circaea lutetiana* L. subsp. *lutetiana* +, *Hypericum androsaemum* L. +, *Ranunculus neapolitanus* Ten. +, *Rumex sanguineus* L. +; **Ril. FS2** *Asplenium scolopendrium* L. subsp. *scolopendrium* +, *Dactylorhiza maculata* (L.) Soó subsp. *saccifera* (Brongn.) Diklić +, *Erica arborea* L. +, *Hypericum androsaemum* L. +, *Laurus nobilis* L. +; **Ril. FS3** *Dactylorhiza maculata* (L.) Soó subsp. *saccifera* (Brongn.) Diklić +, *Ranunculus lanuginosus* L. +; **Ril FS4** *Pulmonaria hirta* L. 1, *Sambucus nigra* L. +; **Ril. FS5** *Silene viridiflora* L. +; **Ril. C1** *Orchis pauciflora* Ten. +, *Trifolium ochroleucon* Huds, +; **Ril. C2** *Cercis siliquastrum* L. subsp. *siliquastrum* 1, *Epipactis helleborine* (L.) Crantz +, *Galium rotundifolium* L. subsp. *rotundifolium* +, *Veronica chamaedrys* L. +; **Ril. C3** *Oenanthe pimpinelloides* L. +; **Ril. C4** *Katapsuxis silaifolia* (Jacq.) Reduron, Charpin & Pimenov +; **Ril. C5** *Silene viridiflora* L. +; **Ril. S1** *Asplenium ceterach* L. subsp. *bivalens* (D.E.Mey.) Greuter & Burdet +, *Cytisophyllum sessilifolium* (L.) O.Lang +, *Geranium versicolor* L. +, **Ril. S2** *Geranium purpureum* Vill. +, *Phillyrea latifolia* L. +, *Polypodium cambricum* L. +, **Ril. M2** *Sorbus graeca* (Spach) hort. Lodd. ex S.Schauer 1, *Tilia platyphyllos* Scop. subsp. *platyphyllos* 1; **Ril. M3** *Asplenium ceterach* L. subsp. *bivalens* (D.E.Mey.) Greuter & Burdet +, *Scutellaria columnae* All. subsp. *columnae* +, *Smilax aspera* L. +

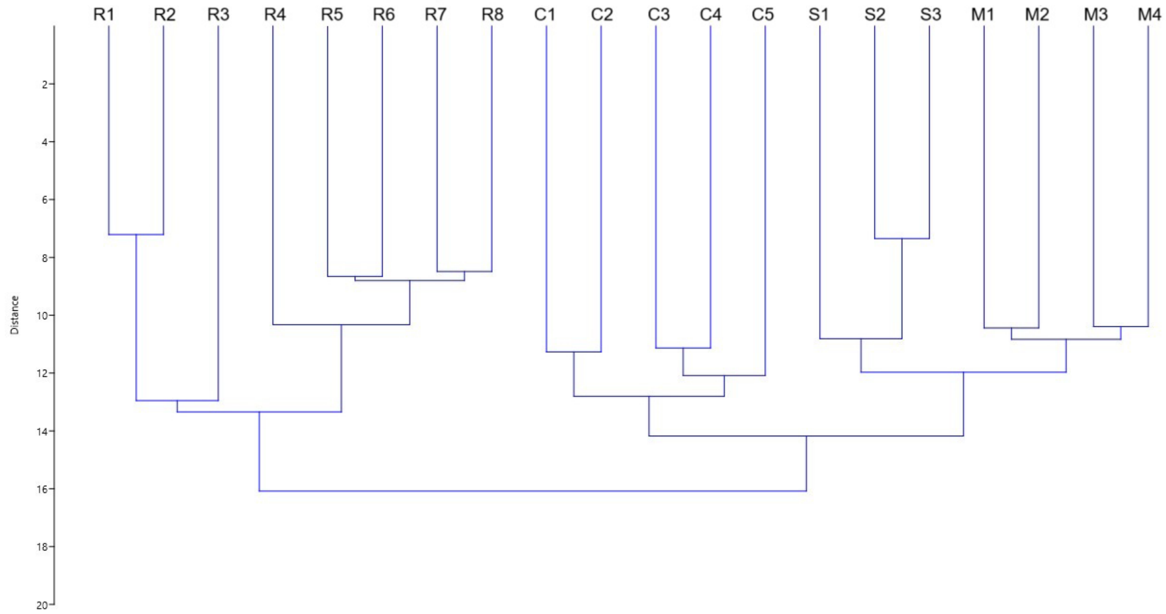

Figure 2: Cluster analysis dendrogram of 20 phytosociological relevés in *Fagus sylvatica* stands, based on species composition. The grouping reflects ecological and biogeographical gradients among the surveyed sites. Relevés from volcanic substrates (Roccamonfina Volcano: R) cluster separately from those on calcareous substrates (Monte Maggiore: M; Monte Cesima: C; Monte Sammucro: S), indicating marked floristic differentiation between geological contexts.

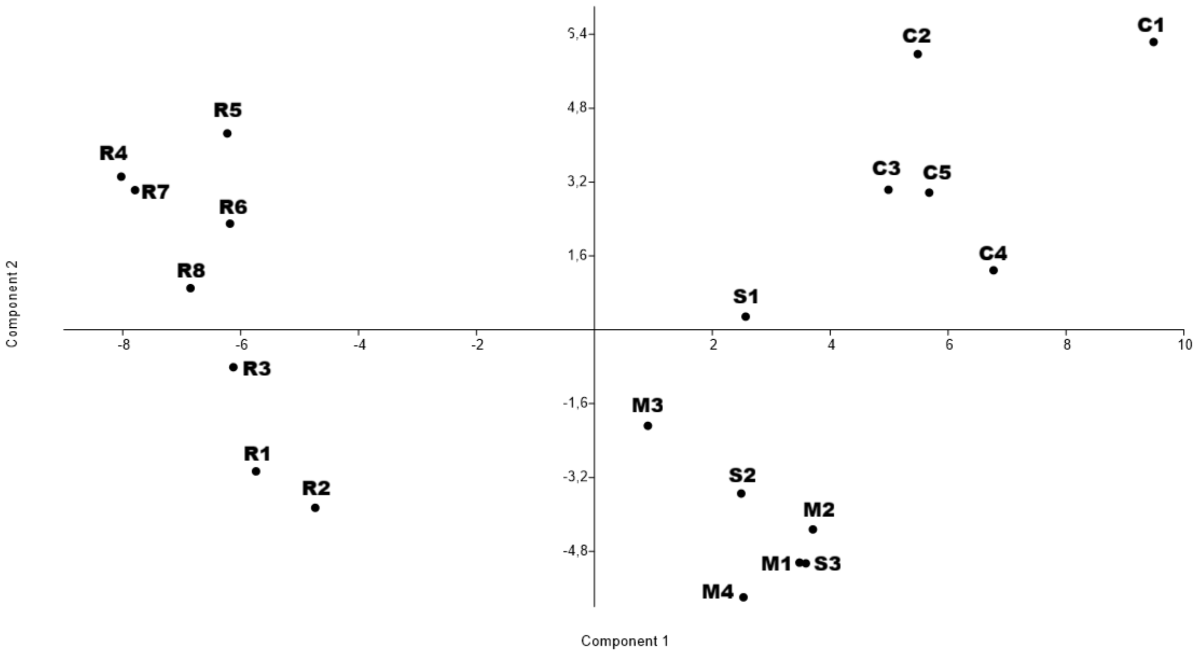

Figure 3: Principal Component Analysis (PCA) of 20 phytosociological relevés in *Fagus sylvatica* stands. The ordination is based on species composition. The first two components explain 32.1% and 14.6% of the total variance, respectively. Letters indicate the different sites: Roccamonfina Volcano (R), Monte Maggiore (M), Monte Cesima (C), and Monte Sammucro (S).

The presence of small beech forest sites represents a crucial element for the conservation of local biodiversity, serving not only as ecological refuges but also as valuable paleogeographic indicators of past climatic and environmental conditions. The high-altitude populations, located on the Tyrrhenian side of the peninsula and within a heavily anthropized landscape, are interpreted as heterotopic relicts—important remnants of a formerly more widespread beech distribution, influenced by geological and climatic history as well as past and present human activity.
Despite their often fragmented and isolated nature, these relict ecosystems host unique assemblages of flora and fauna, contributing significantly to regional ecological networks. It is therefore essential that local authorities implement targeted conservation measures aimed at halting habitat degradation, supporting the natural expansion of beech populations, and safeguarding the integrity of these rare ecosystems. Ensuring their protection is not only a matter of preserving biodiversity, but also of maintaining the historical and ecological memory embedded within these ancient woodlands.

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Husserl and Galileo Notes on '*The Crisis of European Sciences*'

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Abstract

Edmund Husserl's *The Crisis of the European Sciences* (1934–1938) diagnoses modern science as estranged from the concrete world of human experience—the *Lebenswelt*. He identifies Galileo Galilei as the "discovering and concealing genius" whose mathematization of nature produced a science methodologically powerful yet existentially hollow, abstracting from lived experience to deal in idealities. Husserl offers phenomenology as a corrective, restoring subjectivity to the foundations of knowledge. His challenge remains pressing in fields such as neuropsychopharmacology, where subjective states are central but resist quantification. Scientific instruments capture correlates yet miss the lived essence, sometimes distorting method by equating nonpathological drug states with psychosis—a category mistake that treats experience as reducible to measurement. In this essay, I argue that Husserl mischaracterizes Galileo. The basis of modern science lies not in mathematization but rather in Galileo's invention of the experiment as a cycle of imaginative framing, controlled intervention, and theoretical revision. Mathematics reifies, linearizes, and quantifies thoughts that would otherwise remain intuitive and confused. Galileo's pragmatic view of causality—as manipulable conditions rather than metaphysical essences—grounds modern experimental logic. Giambattista Vico later reformulated this idea as *verum esse ipsum factum*: the true is what is made (done). Galileo thus unified imagination, mathematics, and lived practice, even as Husserl's concern about science's neglect of subjectivity endures.

Keywords: G. Galilei, G.B. Vico, epistemology, phenomenology

Riassunto

La Crisi delle scienze europee (1934–1938) di Edmund Husserl diagnostica nella scienza moderna un distacco dal mondo concreto dell'esperienza umana, la *Lebenswelt*. Husserl vede in Galileo Galilei un "genio rivelatore e occultatore": con la matematizzazione della natura avrebbe inaugurato una scienza metodologicamente trionfante ma esistenzialmente vuota, astratta dall'esperienza vissuta. Come rimedio, Husserl propone la fenomenologia, che riporta la soggettività al fondamento della conoscenza. La questione è evidente in campi come la neuropsicofarmacologia, dove gli stati soggettivi sono centrali ma sfuggono all'oggettivazione e alla quantificazione: gli strumenti tecnici colgono correlati, non l'essenza vissuta, talora producendo distorsioni interpretative. In quest'articolo, sostengo che Husserl travisa Galileo. Il fondamento della scienza moderna non è la matematizzazione, bensì l'invenzione dell'esperimento come ciclo assieme immaginativo e pratico: dalla formulazione concettuale all'intervento controllato e ritorno alla teoria, con la matematica usata per reificare, linearizzare, a quantificare l'immaginazione. La concezione galileiana di causalità—cause come condizioni manipolabili piuttosto che essenze metafisiche—disegna per prima la logica sperimentale moderna. Giambattista Vico riprese tale intuizione col motto *verum esse ipsum factum*: il vero è ciò che è fatto. Galileo unì dunque immaginazione, matematica e prassi vissuta, anche se la preoccupazione husserliana sulla rimozione della soggettività rimane attuale.

Parole chiave: G. Galilei, G.B. Vico, epistemologia, fenomenologia

Introduction

Edmund Husserl's *The Crisis of the European Sciences* (1934-1938), published posthumous and unfinished in 1954, is a deeply ambitious and often frustrating text. Part historical diagnosis, part philosophical intervention, it proposes that European science—and, by extension, all modern science—has lost its way by detaching itself from the concrete world of human experience, what Husserl calls the lifeworld [*Lebenswelt*]. The culprit, in his view, is Galileo Galilei, "at once a discovering and concealing genius" (Husserl, 1954/1970, p. 52) whose project of mathematizing nature established a mode of science that abstracts from the lived world of our experience to deal only in idealized geometrical entities. For Husserl, this marks both the triumph and the failure of modern science: a triumph of method, a failure of meaning.

The foundational move Husserl describes—the replacement of intuitive, perceptual givenness with mathematical idealities—is, in his eyes, the source of the present crisis. Science becomes progressively more technical and precise, but also more alienated from the world it seeks to explain. Phenomenology, Husserl argues, must restore the broken link. It must show how all objective knowledge, including science, arises from intentional acts of consciousness. The subject, not the object, must be placed back at the center, but in a manner more rigorous than Descartes was able to achieve with his *cogito*.

Husserl's insight

There is undeniable value in this critique. It is true that modern science conceals—or rather forgets—its origins in lived inquiry, that the data scientists collect are detached from experience. The study of psychoactive drugs, particularly psychedelics, offers an interesting case in point. These agents produce mental experiences that defy description and quantification but are nonetheless central to their actions. Neuroimaging data, behavioral tests, and molecular techniques allow us to identify correlates, but do not capture the core of the phenomenon: the altered consciousness itself. Even the most perceptive of psychological analyses fails to achieve this goal. Discussing mystical experiences, including those induced chemically, William James wrote in 1902: "Although so similar to states of feeling, mystical states seem to those who experience them to be also states of knowledge. They are states of insight into depths of truth unplumbed by the discursive intellect. They are illuminations, revelations, full of significance and importance, all inarticulate though they remain; and as a rule they carry with them a curious sense of authority for aftertime" (James, 1902/1982). Anyone who has had an experience of this kind—James called them *noetic*—can attest to the uncanny accuracy of this statement. Yet, no one can go beyond the paradox that what feels most real eludes empirical validation, as none of our models or measurements captures this reality as it is lived.

This split between empirical data and lived experience exemplifies what Husserl diagnosed as a crisis: the disconnection of scientific inquiry from the *Lebenswelt*, the lifeworld of direct, embodied experience. This is evident throughout the field of neuropsychopharmacology, where the boundary between the 'objective' and the 'subjective' is inherently porous. Yet conventional scientific frameworks demand a clean separation between them, periodically leading researchers into conceptual cul-de-sacs. This point is illustrated vividly by investigations on Δ^9-tetrahydrocannabinol (THC), the psychotropic constituent of *Cannabis sativa* (L.). Under certain conditions, THC can elicit experiences that closely resemble those produced by classical psychedelics, like psilocybin or LSD.[1] However, to quantify and categorize these effects, researchers often rely on psychosis rating scales—tools designed to detect pathological conditions such as schizophrenia rather than intentionally sought experiences. This methodological choice equates the cannabis-induced state with a psychotic episode, unnecessarily pathologizing it.

Such framing is, borrowing Gilbert Ryle's term, a *category mistake*—the logical error of assigning something to the wrong conceptual category (Ryle, 1949/2002). Like other such mistakes, it not only misrepresents the phenomenon itself but also forecloses the possibility of understanding it on its own terms. This problem extends to most classes of drugs that directly or indirectly modify brain activity, a fact exploited in pharmacology through the *drug discrimination test*. Developed by Paul Janssen and collaborators in the 1960s and '70s (Colpaert et al., 1976) this behavioral paradigm leverages an animal's ability to recognize and respond to the interoceptive cues produced by specific classes of drugs—or even different doses of the same drug. Its remarkable sensitivity demonstrates that animals can identify these interventions by the *way they feel*—their subjective signature. Disciplines as diverse as neuropsychopharmacology and animal cognition, pain research and consciousness studies all face this problem: how to account for phenomena that are accessible only through subjective experience, yet fundamental to the effects being investigated. What should an empirical scientist do when experience itself becomes the datum? The task here is not to devise better descriptive or measuring tools—the scientist's default course of action—nor to note that something ontologically subjective can still be epistemologically objective—as John Searle would correctly point out (Searle, 1995). Rather, it is to reconsider critically the place of subjectivity within the scientific enterprise.

[1] The profound psychedelic effects of cannabis preparations containing high concentrations of THC are described by early European users—most famously, members of the Parisian *Club des Hachichins*— who consumed it in a fat-rich medium and on an empty stomach—both likely to increase the drug's absorption.

This is not a new concern[2] and is not one that we can take on here, beyond acknowledging its importance. It is time for us to turn to what I consider the key flaw in Husserl's analysis.

Galileo and the grounding of modern science

It is not Galileo's mathematization of nature that grounds the modern scientific enterprise, but rather his invention of the modern experiment. This distinction is critical. The Galilean experiment is a structured practical activity in which a possible portion of the world is first imagined and then physically constructed in a controlled setting[3]. Before becoming a formal method, it's an attitude toward the world. An attitude that we see unfold across Galileo's entire life work. Between 1582 and 1583, while still in his late teens, he noticed that a swinging lamp in the cathedral of Pisa took the same amount of time for each oscillation, regardless of the arc's amplitude. He measured it using his own pulse as a chronometer, recognizing what is now called *isochronism*—the approximate equality of swing periods for small-angle pendulum oscillation. Just a few years later, in 1586, he designed and built a hydrostatic balance to measure the specific weight of different bodies, describing it in a short treatise that circulated only in manuscript form. These anecdotes frame Galileo's lifelong conviction that practice—not abstract logical or mathematical principles—is foundational to scientific knowledge. This same conviction would lead him to perfect the telescope and aim it at the heavens rather than at enemy armies or ships at sea, as its Dutch inventors had done, discovering in 1610 Jupiter's satellites, the Moon spots, and the phases of Venus.

For Galileo, the scientist's task is to imagine a theoretical scenario, create controlled physical conditions under which it might (or might not) be realized, and then interpret its outcome. Mathematics is critical during both the ideation and the interpretation of the experiment but, he held, when theory and observation conflict, empirical evidence must prevail: "Did he not assert," asks Salviati in the *Dialogue Concerning the Two Chief World Systems* (1632) "that what experience and the senses show us must be placed before any reasoning, even though that reasoning might seem very well founded?" (Galilei, 1632/1970) Salviati's words mirror Galileo's own views and stands in stark contrast to those Husserl attributed to him: "For [Galileo]," the philosopher wrote, "a physics was immediately almost as certain as the previous pure and applied mathematics." (Husserl, 1954/1970, p. 39). More critically, never in *The Crisis* does Husserl mention Galileo's insistence on the importance of experimentation and science's grounding in lived practice.

Yet, the Galilean experiment—and, by extension, all modern experimental science—is irreducibly practical and active. It proceeds neither solely from experience toward abstraction, nor from abstraction toward experience. It is better described as a cycle: from thought to practical intervention, back to thought. The language of mathematics plays a special role in this process, enabling the reification, linearization, and quantification of thoughts that words alone would convey only intuitively and confusedly. Since a young age, Galileo had shown a deep love for mathematics and—likely influenced by the Platonic views of many of his Florentine contemporaries—believed that Nature itself was imbued with it: "Philosophy—he writes in an oft-cited passage—is written in this grand book, I mean the

[2] Thomas Nagel and others have long argued that subjective experience—what it is like to be a bat, or a human on LSD—is irreducible to objective description (Nagel, 1974).

[3] The laboratory experiment is one instance of the modern experiment. I use the term to encompass all scientific activities that require empirical verification—from molecular biology to paleontology and including theoretical sciences insofar as their conclusions remain hypothetical until verified.

universe, which is continually open in front of our eyes. But the book cannot be understood unless one first learns to comprehend the language and read the letters in which it is composed. It is written in the language of mathematics, and its characters are triangles, circles, and other geometrical figures, without which it is humanly impossible to understand a single word of it; without these, one wanders about in a dark labyrinth." (Galilei, 1623/1977)
Nevertheless, even when an experiment begins as a mathematically framed question and ends with a mathematical interpretation of the results, it would not be scientific without the intermediate step of empirical verification. As Galileo has Salviati say in the *Dialogue Concerning the Two Chief World Systems*: "This [experimentation] is the custom, and properly so, in those sciences where mathematical demonstrations are applied to natural phenomena, … where the principles, once established by well-chosen experiments, become the foundations of the entire superstructure" (Galilei, 1632/1970).

Galileo's notion of causality further underscores his epistemic stance. Aristotle had insisted that all knowledge is knowledge of causes: "We do not have knowledge of a thing—he wrote in the second book of *Physics*—until we have grasped its why [διὰ τί]—that is, its cause [αἴτιον]" (Aristotle, 1934). But whereas Aristotle regarded causes as metaphysical essences, Galileo took a radically different view. In the *Discourses and Mathematical Demonstrations Concerning Two New Sciences* (1638), Salviati explains: "The present does not seem to be the proper time to investigate the cause of the acceleration of natural motion concerning which various opinions have been expressed by various philosophers, some explaining it by attraction to the center, others to repulsion between the very small parts of the body, while still others attribute it to a certain stress in the surrounding medium. It is sufficient for our Author that we understand him to mean by uniformly accelerated motion one in which the velocity increases by equal amounts in equal times. If therefore we find that the properties which he deduces correspond to those which are observed in nature, we may conclude that his assumption was correct" (Galilei, 1638/2003). Speaking for Galileo, Salviati thus declines to pursue the cause of acceleration in Aristotle's sense, attending instead to the measurable properties of naturally accelerated motion. Galileo's position on causality is articulated even more clearly in the earlier anti-Aristotelian *Discourse on Floating Bodies* (1612): "Cause is that which, when present, brings about the effect; and when removed, takes the effect away" (Galilei, 1612/1968)—a formulation whose pragmatic clarity foreshadows both interventionist accounts of causality and the logic of contemporary biology, where the functions of genes and proteins are investigated through loss- and gain-of-function approaches that either disrupt or enhance their activity.

Galileo was not interested in philosophical disputes and did not leave a formal description of his experimental method. Modern interpretations are often unsatisfactory. Eugenio Garin described Galileo reasoning as "analysis and resolution, which proceeds from experimental data to reach the mathematical structure that constitutes the backbone of reality," (Garin, 1978) undervaluing—in my reading—the epistemic role of practice. More recently, Gregory Dawes observed that Galileo's method "resembles speculative natural philosophy insofar as its probative force depends upon a priori, mathematical reasoning, but it also resembles experimental natural philosophy insofar as the principles of such reasoning are tested against experience" (Dawes, 2016). Though historically grounded, the juxtaposition between speculative and experimental natural philosophy fails to capture the full consequences of integrating the language of mathematics and the practice of experiment. This integration harnesses the narrative drive of the human mind—our innate impulse to make sense of the world using language-based accounts, including mathematics—to imagine possible realities and guide exact physical experimentation that tests their factual validity. In the words of Ludovico Geymonat: “To understand Galileo’s method one must understand how he combined [experiment and mathematics], transforming them in a single process that is both rational and empirical” (Geymonat, 1970). For us—who are born and live in a world permeated by numbers, science and technology—appreciating the significance of this epistemic leap requires a considerable effort of imagination.

The Catholic Church, however, immediately recognized its revolutionary impact. The publication of Nicolaus Copernicus’s *De revolutionibus orbium coelestium* (1543) had left the ecclesiastic authorities largely unfazed. In the words of cardinal Roberto Bellarmino, who played a pivotal role in defining the Church’s stance on heliocentrism: “To suppose that the Earth moves and the Sun remains stationary preserves all the appearances better than introducing eccentrics and epicycles; this is very well said and poses no danger, and it is sufficient for the mathematician. But to assert that the Sun truly occupies the center of the world, rotating only on its own axis without moving from east to west, and that the Earth occupies the third sphere and spins rapidly around the Sun, is a very dangerous claim…” (Bellarmino, 1615/1989). Copernicus’ elegant calculations posed no threat to the established world order. Galileo’s unprecedented use of mathematics, by contrast, carried profound implications: it leveraged the reifying, linearizing, and quantifying power wielded by this language to transform thought into symbol and number, both into practice, and practice into secure knowledge, opening entirely new cognoscitive horizons.

The true is what is made

The extraordinary success of Cartesian epistemology, with its improbable grounding of certainty in clear and distinct ideas, all but buried Galileo’s insight that true knowledge is fully achieved only in an act of making. That insight, however, resurfaced less than a century later in Giambattista Vico’s first major philosophical work: *On the most ancient wisdom of the Italians* (1710) (Vico, 1710/1988a). The treatise opens with an abrupt and explicitly anti-Cartesian assertion: *verum esse ipsum factum*, the true is precisely what is made (or done). The intellectual origin of this maxim, which Vico traces to the Latin usage of *verum* and *factum* as synonyms, remains debated. What is clear, however, is that the maxim shifted the dominant model of knowledge: from viewing the knower as a passive contemplator of fixed ideas or internal impressions to understanding them as an active creator of truth. As Vico clarifies: “… hypotheses about the natural order are considered most illuminating and are accepted with the fullest consent of everyone, if we can base experiments on them, *in which we make something similar to nature* [emphasis mine]” (Vico, 1710/1988, p. 52). Truth for him arises—through the process of metaphorical thinking—within the products of imitative human activity. It is not guaranteed by God, as Descartes maintained, but by our own cognoscitive powers. Vico carried this principle into the *New Science* (1744), with his attention now firmly turned toward human history: “But, in such a dense night of thick darkness that covers antiquity—Vico writes opening the book’s third section (*On principles*)—that light which can lead us out of so great an obscurity must be taken as a principle: namely, that this world of civil society has certainly been made by men, and therefore its principles must be found within the modifications of our own human mind.” (Vico, 1744/1942, p.117).

From Jules Michelet onward, most interpreters have justifiably focused on the anthropological and historical aspect of Vico’s thought (Michelet, 1837). But Vico, like other members of the contemporary Neapolitan *Academy of the Investigators*, also nurtured a vivid interest in the natural sciences. Three years before publishing *On the Most Ancient Wisdom of the Italians*, he composed a short essay—*On the Balance of the Living Body*—concerned with mechanics and physiology. Possibly influenced by the works of fellow citizens Giovanni Alfonso Borelli (1608-1679) and Leonardo di Capua (1617-1695), the treatise is now lost, leaving us only to speculate about its contents and significance. Yet the principles Vico articulates in his later work make his position clear: we cannot fully know Nature itself, since we are not its makers. What we can and do know—*ex intus,* as it were—is the incessant human labor of modifying Nature and creatively imitating it, including through the practice of the modern scientific experiment. Like the products of our activity, science is accessible (knowable) to us because it is of our own making—its empirical truth borne out in the unending generative power of its constructs. That these constructs reshape material, intellectual, and social life attests to their reality.

Conclusions

Let us return to Husserl. I have argued that his critique of Galileo as "at once a discovering and concealing genius" is unfounded: Galileo did not mathematize the world in abstraction from the intentional human experience of the *Lebenswelt*; on the contrary, he bound them together through the intentional practice of the experiment, driven by the immense combined forces of imagination and mathematics. Vico intuited the significance of this advance and recast it in the philosophical language of his time, turning Descartes' logic on its head.

Yet Husserl's judgment of post-Galilean science as a triumph of method and a failure of meaning still stands. This failure manifests not only in science's inability to acknowledge subjectivity as a datum, as I noted earlier, but even more so in a growing chasm— between science and the public, between scientific and humanistic disciplines, and between scientists, increasingly reduced to "highly brilliant technicians of method" (Husserl, 1954/1970, p. 56), and the meaning and goals of their own work. In this light, Husserl's project remains unfinished, and perhaps more urgent than ever.

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South-risk, South-safety: the lightning rod in enlightenment Naples

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Abstract

The Enlightenment's pursuit of natural philosophy found fertile ground in Naples, which became a leading center for the dissemination of Newtonian physics and the study of electricity. Within this intellectual climate, a network of scholars, including Della Torre, Bammacaro, Ardinghelli, and Poli, fostered experimentation, technological innovation, and early strategies for confronting environmental risk. This study examines the introduction of lightning rods in Naples as both a scientific breakthrough and a symbolic gesture of risk mitigation. British diplomat William Hamilton played a pivotal role in promoting their adoption, notably through the Italian translation of *Chiare istruzioni per costruire ed innalzare sicuri conduttori*, translated by astronomer Felice Sabatelli. By making Franklin's theories on electrical conductors accessible to Italian audiences, the pamphlet helped foster a new culture of safety and public awareness. Naples thus emerges as a pioneering site where vulnerability catalyzed technological ingenuity and cultural transformation.

Keyword: History of Physics - Electricity - Lightnings - Conductors - Risk Culture - Naples

Riassunto

La filosofia naturale promossa dagli ambienti illuministi trovò terreno fertile a Napoli che divenne un centro di riferimento per la diffusione della fisica newtoniana e per lo studio dell'elettricità. In questo vivace clima intellettuale, una rete di studiosi, tra cui Della Torre, Bammacaro, Ardinghelli e Poli, promosse la sperimentazione, l'innovazione tecnologica e le prime strategie per affrontare il rischio ambientale. Questo studio analizza l'introduzione dei parafulmini a Napoli come svolta scientifica e, al tempo stesso, come gesto simbolico di mitigazione del rischio. Il diplomatico britannico William Hamilton svolse un ruolo decisivo nel promuoverne l'adozione, anche attraverso la pubblicazione di *Chiare istruzioni per costruire ed innalzare sicuri conduttori*, tradotto in italiano dall'astronomo Felice Sabatelli. Rendendo accessibili al pubblico italiano le teorie di Franklin sui conduttori elettrici, il libretto intendeva contribuire a diffondere una nuova cultura della sicurezza e della consapevolezza pubblica. Napoli emerge così come un luogo pionieristico in cui la vulnerabilità ha catalizzato l'ingegno tecnologico e la trasformazione culturale.

Parole chiave: Storia della Fisica - Elettricità - Fulmini - Parafulmini - Cultura del Rischio - Napoli

Introduction

Throughout history, lightning has inspired a wide range of interpretations, reflecting the evolution of human thought and the transformation of scientific paradigms. From antiquity to modernity, observations of electrical phenomena gradually moved beyond mythical and divinatory frameworks, embracing experimental inquiry and instrumental analysis. Philosophers such as Thales, Plato, and Pliny the Elder had already noted the attractive properties of amber (ἤλεκτρον in Greek), anticipating the notion of an invisible force. The term ēlektron first appears in Homer's Odyssey (Book IV), when Telemachus admires amber-inlaid decorations on the walls of King Menelaus' palace in Sparta. The word shares an Indo-European root with ἠλέκτωρ, meaning "shining sun", suggesting that amber was primarily valued in antiquity for its brilliance and luminous quality.

Among natural phenomena, lightning remains one of the most powerful and awe-inspiring manifestations of electrical energy. In ancient cosmologies, it was regarded as a principal attribute of deities such as Zeus, Teshub, and Thor, conceived as the meteorological expression of divine will.

In his *Meteorologica*, Aristotle proposed a naturalistic explanation, attributing lightning to dry exhalations released from clouds during the condensation of air, producing thunder through collision:

> "*Etsi fulmen nomen commune sit ad omnem exhalationem quae e nube erumpit eiaculaturquae ardens: peculiare tamen ipsum faciunt ad eam quae nubem prumpit & fulgetrum nuncupant eam quae longiore tractu nubem findit*". (Aristoteles, 1512, f. LXXV)

Five centuries later, Pliny the Elder, in his *Naturalis Historia*, expanded on the topic by referring to Etruscan traditions, which viewed lightning as divine messages:

Tuscorum literae novem Deos emittere fulmina existimant, eaque esse undecim generum: Iovem enim trina iaculari. (Plinius Secundus, 1831, p. 166)

He distinguished between dry, wet, and bright lightning, each bearing ritual and divinatory significance. Struck locations, named *bidentalia,* were considered sacred, and lightning itself was categorized as "familiar" or "infernal", believed to be summonable through specific ceremonies. This theological-natural conception embedded atmospheric electricity within a ritual and augural system:

> "*Fulminum ipsorum plura genera traduntur. quae sicca veniunt, non adurunt, sed dissipant; quae umida, non urunt, sed infuscant. tertium est quod clarum vocant, mirificae maximae naturae, quo dolia exhauriuntur intactis operimentis nulloque alio vestigio relicto, aurum et aes et argentum liquatur intus, sacculis ipsis nullo modo ambustis ac ne confuso quidem signo cerae*". (Plinius Secundus, 1831, p. 166)

The transition to a scientific understanding of lightning unfolded gradually. In 1600, William

Gilbert (Fig. 1) introduced the term *electrica* to describe the behavior of rubbed amber (Gilbert, 1600, p. VIr), as he demonstrated during a presentation for Queen Elizabeth (Fig. 1). In 1646, Thomas Browne was the first to use the term *electricity* in its modern sense, contributing to the lexical foundation of a field that would evolve autonomously in the centuries to follow.

This article analyzes the development of atmospheric electricity theories, with particular focus on the urban and scientific context of 18th-century Naples. Through the examination of documentary sources, it traces key stages in a cultural and epistemological transition: from sacred vision to physical-natural interpretation; from symbolic risk to technical planning; from *South-risk*, marked by exposure and vulnerability, to *South-safety*, understood as a culture of prevention and rationality.

Figure 1: *Dr. William Gilberd demonstrating his experiments on electricity to Queen Elizabeth and her court.* Painted by Arthur Ackland Hunt, 19th century. Credit: Colchester and Ipswich Museums.

The Concept of Electricity Between the 17th and 18th Centuries

At the close of the 16th century, William Gilbert laid the groundwork for the systematic study of electrical phenomena in his treatise *De Magnete*. Observing that certain materials, when rubbed, emitted an invisible effluvium capable of attracting light objects such as paper fragments, Gilbert hypothesized the existence of an undefined natural force. He invented the *versorium*, a device with a rotating needle that anticipated the principle of the electroscope (Heilbron, 1979, pp. 169-179). Brilliant though his insights were, they remained steeped in philosophical analogies, reflecting the transitional nature of early scientific thought.

With the dawn of the 18th century, lightning began to be interpreted not as an isolated celestial event, but as an atmospheric manifestation linked to observable electrical properties. In 1709, Francis Hawksbee introduced glass globes to generate electricity and studied the behavior of electrical light in a vacuum. Soon after, Stephen Gray and Reverend Granville Wheler demonstrated the transmission of electricity over long distances, contributing to the concept of the insulated conductor. Their experiment, using a hemp cord suspended with silk supports, highlighted the importance of insulation in preserving electrical charge (Heilbron, 1979, pp. 229-234).

In the following decade, attention turned to rotating machines capable of producing sparks visible even in daylight, leading to a new generation of electrostatic devices. In parallel, the atmospheric phenomenon of lightning began to be associated with the electrical fluid studied in laboratories.

Benjamin Franklin, renowned as one of the founding fathers of the United States of America, was also a pioneering scientist and inventor whose contributions to the study of electricity had profound implications for both scientific progress and public safety. Among his most influential innovations was the lightning rod: a device that came to symbolize the Enlightenment's union of reason, experimentation, and civic utility.

Franklin's *Experiments and Observations on Electricity*, published in 1751, established what many regard as the first coherent paradigm of electrical theory. In respect to the models proposed by his contemporaries, Franklin's framework was clear and practical. He conceived electricity as a single elastic fluid, governed not by collision but by forces of attraction and repulsion (Pense, nd).

Building on this theoretical foundation, Franklin began to explore practical applications of electrical principles. As early as 1749, he hypothesized that lightning was a natural manifestation of electrical phenomena (Franklin, 1961a). In his *Opinions and Conjectures concerning the Properties and Effects of the Electrical Matter, arising from Experiments and Observations made in Philadelphia, 1749*, sent to the botanist Peter Collinson dated 29 July 1750, Franklin proposed a simple experiment to test the electrical nature of lightning:

> "*On the Top of some high Tower or Steeple, place a Kind of Sentry Box big enough to contain a Man and an electrical Stand. From the Middle of the Stand let an Iron Rod rise… pointed very sharp at the End… a Man standing on it when such Clouds are passing low, might be electrified, and afford Sparks, the Rod drawing Fire to him from the Cloud*". (Franklin, 1961b)

Furthermore, Franklin outlined the first description of the power of points, which could:

> "*be of Use to Mankind in preserving Houses, Churches, Ships &c. from the Stroke of Lightning; by Directing us to fix on the highest Parts of those Edifices upright Rods of Iron, made sharp as a Needle and gilt to prevent Rusting, and from the Foot of those Rods a Wire down the outside of the Building into the Ground; or down round one of the Shrouds of a Ship and down her Side, till it reach'd the Water… These pointed Rods… thereby secure us from that most sudden and terrible Mischief!*" (Franklin, 1961b)

In this way, Franklin proposed that electrical charge might be siphoned from the clouds without producing a violent discharge. Alternatively, if a building were struck directly, the destructive power could be channeled away from the structure using a conductive wire,

Figure 2: *Benjamin Franklin Drawing Electricity from the Sky*, painted by Benjamin West, ca. 1816. Tribute to Franklin's 1752 experiment proving the electrical nature of lightning. Credit: Philadelphia Museum of Art.

much like how damp clothing might redirect lightning away from a person's body, reducing the risk of injury.

While the sentry box experiment remained theoretical, Franklin famously demonstrated the electrical nature of lightning in June 1752 with his iconic kite experiment. He launched a silk kite fitted with a metal tip and grounded via a key, allowing electricity to be drawn from storm clouds and confirming the link between atmospheric phenomena and electrical discharge (Fig. 2).

The experiment was described in the *Pennsylvania Gazette* on 19 September of that year:

> "*This Kite is to be raised when a Thunder Gust appears to be coming on, and the Person who holds the String must stand within a Door, or Window, or under some Cover, so that the silk Ribbon may not be wet; and Care must be taken that the Twine does not touch the Frame of the*

Door or Window. As soon as any of the Thunder Clouds come over the Kite, the pointed Wire will draw the Electric Fire from them, and the Kite, with all the Twine, will be electrified, and the loose Filaments of the Twine will stand out every Way, and be attracted by an approaching Finger. And when the Rain has wet the Kite and Twine, so that it can conduct the Electric Fire freely, you will find it stream out plentifully from the Key on the Approach of your Knuckle. At this Key the Phial may be charg'd; and from the Electric Fire thus obtain'd, Spirits may be kindled, and all the other Electric Experiments be perform'd, which are usually done by the Help of a rubbed Glass Globe or Tube; and thereby the Sameness of the Electric Matter with that of Lightning compleatly demonstrated". (*Philadelphia*, October 19, 1752)

From these observations, the lightning rod was born: a pointed metal conductor mounted atop a structure and connected to the ground via an insulated wire, designed to safely disperse electrical energy (Heilbron, 1979, pp. 324-343; Krider, 2006).

Through these discoveries, Franklin advanced scientific understanding, and exemplified the Enlightenment ideal of knowledge applied in service to society.

However, Franklin's proposal sparked a heated debate with English scholar Benjamin Wilson, who argued that pointed tips were too attractive and advocated for spherical terminations, which he believed were less likely to provoke discharges. The controversy peaked in 1777, when lightning struck a powder magazine in Purfleet-on-Thames despite the presence of Franklin-style tips. Wilson staged a public demonstration at London's Pantheon, showing how pointed conductors could attract discharges even from significant distances. King George III supported Wilson's position, and for several years, blunted versions were officially adopted (Tunbridge, 1974).

On the European continent, a key figure in the dissemination of Franklin's theories was the French naturalist Thomas-François Dalibard, who translated Franklin's works into French alongside the eminent scholar Georges-Louis Leclerc, Comte de Buffon. On 18 May 1752, Dalibard conducted the first European experiment aimed at capturing atmospheric electricity, installing an insulated metal rod in Marly-la-Ville, near Paris. Although Dalibard oversaw the installation, he was recalled to Paris on urgent business before the experiment could be conducted. In his absence, the task was entrusted to Coiffier, a resident and former dragoon cavalry soldier, whose reliability and courage Dalibard valued. The Prior of Marly, Raulet, later had Coiffier deliver a letter announcing the experiment's success.

Dalibard's successful experiment, conducted weeks before Franklin's own, marked a turning point in European scientific discourse. It confirmed the electrical nature of lightning and helped legitimize the lightning rod within academic circles (Krider, 2006). During a session of the Académie Royale des Sciences on 13 May, Dalibard read his memoir *Des expériences et observations sur le tonnerre relatives à celles de Philadelphie*, declaring: "The idea conceived by Mr. Franklin is no longer a conjecture; it has now become a reality".

Jean-Antoine Nollet and the Theory of the Double Fluid

Among the most significant figures in the development of 18th-century electrical physics, Abbé Jean-Antoine Nollet occupies a central place. A student of Du Fay and Réaumur, he engaged with prominent advocates of Newtonian physics, including John Theophilus Desaguliers and Willem Jacob 's Gravesande. Nollet was among the first to draw an analogy between electricity and lightning, and his theories advanced the understanding of charge attraction and dispersion.

His theory of electrical fluid rested on the existence of two subtle, invisible components: the *effluent* (outward flow) and the *affluent* (inward flow), which corresponded to opposing directions of electrical movement through the pores of electrified bodies. Expanding on Du Fay's model of vitreous and resinous fluids, Nollet envisioned these flows as opposing polarities responsible for phenomena of attraction and repulsion (Heilbron, 1979, pp. 346-362).

A particularly significant chapter in Nollet's intellectual trajectory unfolds through his encounter and subsequent correspondence with Maria Angela Ardinghelli, partially included in *Lettres sur l'électricité* (1753 and 1767), translated into Italian two years later. The volume consists of a series of unsent letters, many of them addressed to Benjamin Franklin, in which Nollet defends his own theories on electricity while critically engaging with Franklin's experimental claims. In his letter to Ardinghelli, Nollet commented on Franklin's work with a tone that subtly asserted European scientific primacy: "[Although] Mr. Franklin appears in his observations to be very ingenious and perceptive… [it is] quite likely that a man of the New World, residing in a colony where commerce is valued more than science, may have been unaware of what was taking place in Europe regarding electricity". While Nollet recognized the experimental validity of Franklin's observations, he approached overly optimistic interpretations with caution, fearing that "a real discovery might be abused" through premature generalizations. His theoretical prudence, steeped in epistemological depth, helped establish a more nuanced and critical interpretive framework for atmospheric electricity.

Nollet met Ardinghelli in Naples in 1749, during his travels in Italy, and was immediately struck by her scientific acumen and clarity of thought. Although the letter addressed to her was never sent, it reflects a genuine intent to engage in dialogue and stands as a rare instance of intellectual exchange, albeit one-sided, between a French academic and an Italian woman scholar. The text offers a vivid glimpse into the theoretical controversies of the time, with Ardinghelli emerging as a rigorous, incisive, and original interlocutor. Nollet openly acknowledges her authority and receives her insights with marked respect and attentiveness (Bertucci, 2013).

Figure 3: Lightning rod on the Padua Observatory, installed by Giuseppe Toaldo in 1773. Illustrated in a 1774 engraving by Franco Castellani and Giuseppe Zulian. Credit: Deutsches Museum.

Although a lightning rod was installed on a public building in Paris - the Louvre - in 1782, the concept had already inspired creative expressions within French culture well before its official adoption. In 1773, Jacques Barbeu du Bourg, a French translator of Franklin's works, proposed a "parapluie paratonnerre": an umbrella equipped with an iron rod, grounded by a trailing wire. This fusion of utility and spectacle soon found expression in Parisian fashion. For a brief period, women adopted a fashionable reinterpretation: a tall, wide-brimmed conical hat adorned with feathers and edged with metallic wire, which connected via a silver chain to the wearer's heels. In this instance, fashion appropriated scientific principles to protect the coiffed heads of Parisian elites from celestial fire: the "chapeau paratonnerre" (Figuier, 1868, p. 568, 597).

Italian Contributions to Atmospheric Electricity Studies

In the European scientific landscape of the eighteenth century, Italy played a pivotal role in advancing the study and application of atmospheric electricity. Prominent scholars such as Giuseppe Veratti, Giovanni Battista Beccaria, and Giuseppe Toaldo helped legitimize Benjamin Franklin's theories and transform them into practical innovations in urban planning, architecture, and public safety.

Giovanni Battista Beccaria, a physicist and mathematician from Piedmont, was among the first in Europe to replicate Franklin's experiments. In his *Dell'elettricismo artificiale e naturale* (1753), he endorsed the theory of electrical fluid and demonstrated its physical and measurable nature through rigorous experimentation. His contribution extended beyond theoretical discourse: on 2 July 1752, he installed lightning rods on his own residence in Turin to replicate phenomena previously observed by French physicists. A year after publishing his treatise, he further tested the device's effectiveness by placing two insulated metal rods on the Valentino Castle. In 1764, he proposed equipping Milan Cathedral with a lightning rod, an unprecedented move that marked a turning point in the protection of public buildings. His correspondence with Franklin and membership in the Royal Society attest to his international recognition (Proverbio, 2001).

In Bologna, Laura Bassi and Giuseppe Veratti initiated a period of intense experimentation on electricity. In 1746, they equipped their laboratory with a machine inspired by the model developed by Hauksbee. Two years later, Bassi presented to the Academy of Sciences of Bologna her treatise *De aere in fluidis contento*, in which she expressed a keen interest in contemporary debates on electricity. She drew an analogy between the behavior of air and that of light, noting that both, like electricity, obey the laws of attraction and repulsion and tend to accumulate at the extremities and corners of bodies (Cavazza, 2009).

Bassi and Veratti embraced the theory of a single electrical fluid formulated by Franklin and supported in Italy by Beccaria, including the hypothesis regarding the electrical nature of lightning. In July 1752, Veratti replicated the experiment conducted by Dalibard at the observatory of the Institute of Sciences in Bologna. With the assistance of the astronomer Petronio Matteucci, along with the young Tommaso Marino, Gabriele Brunelli, and Antonio Paganuzio, Veratti installed a long metal rod atop the tower of Palazzo Poggi. During a thunderstorm, he successfully obtained electrical sparks, thereby providing experimental confirmation of Franklin's theory. In a detailed account, Veratti wrote:

> *"The electrical principle is diffused throughout nearly all terrestrial bodies... Yet almost no one had claimed that it also pertained to clouds and celestial bodies... The first to attempt something, as far as we know, was Franklin in America... To ensure that Italian experiments were not lacking, I decided to conduct trials myself... On 27 July, around fourteenth hour* [approximately 11:15 of 28 July]*, the sky darkened with thick black clouds... small flashes of lightning appeared and faint thunder was heard...* [after a while] *I approached the key and touched it: I found it electrified, with very clear sparks emerging from it... They lasted for seven minutes and were beautiful. Suddenly, a bolt of lightning struck, and the person holding the iron rod with his right hand... was shaken with such violence throughout the right side of his body that words cannot describe it; the pain extended to his foot and persisted for many hours"*. (Veratti, 1755)

The experiments were repeated in the following days with similar results. However, the intensity of the electrical discharges and the direct involvement of the experimenters raised serious concerns among local authorities. The ensuing controversy led to the suspension of the trials and a prohibition on installing lightning rods on public buildings, despite their proven effectiveness (Cavazza, 2009).

The Padua astronomer Giuseppe Toaldo emerged as another key figure in the Italian reception of Franklin's theories. Appointed professor of astronomy in 1762, he supported Franklin's theories and opposed the cautious stance of the French school led by Nollet. His treatises *Della maniera di difendere gli edificj dal fulmine* (1772), and *Dell'uso de' conduttori metallici a preservazione degli edifizj contro de' fulmini* (1774) promoted the use of lightning rods, overcoming both popular

Figure 4: A group of scholars, including Della Torre and Ardinghelli, engaged in early electrical demonstrations within the scientific circle at the palace of Prince Spinelli di Tarsia. Engraving from *Scienza della natura*, vol. 2. Credit: Astronomical Observatory of Capodimonte.

and religious resistance. Toaldo implemented protective systems atop churches and bell towers, including that of St. Mark in Venice, as well as on the Padua Observatory (Fig. 3), and even on Venetian naval vessels (Lepschy, 1998).

In 1769, Grand Duke Pietro Leopoldo of Lorraine ordered the creation of a network of lightning rods to safeguard the powder magazines of Tuscany's major cities. The first Franklin-type device was erected in Siena on the Torre del Mangia in September 1776, under the supervision of physicist Domenico Bartaloni and architect Antonio Matteucci (Bartaloni, 1781). The decision met with significant resistance, fueled by the widespread belief that such instruments attracted lightning rather than protected buildings and people from its strikes, as reported by the mathematics professor at the University of Siena, Andrea Pistoi, wrote:

> *"The people who do not study physics cannot so easily be persuaded of the usefulness of new discoveries, and some, mockingly, when the electric pole was being installed, called it the 'heretical pole'. Yet the Sienese people, docile and curious by nature, are inclined to embrace any novelty and to admire its inventor as soon as they are in some way convinced of its truth and usefulness. It will be helpful, for greater understanding, to first explain the nature of the conductor"*. (Pistoi 1781)

That skepticism was dispelled the following year, on 18 April 1777 when the lightning rod proved its full effectiveness. Pistoi commented:

> *"The Sienese people, always sensitive and grateful toward those who do good for humanity, are surprised that statues are so often raised to those who have ruined cities, and so rarely to those who preserve them. Mr. Franklin... will surely feel an ineffable consolation in hearing of his great triumph and the praise bestowed upon him by peoples so distant from his homeland, who see in his prodigious rod the most conspicuous trophy of the greatness of his immortal genius"*. (Pistoi 1781)

Remarkably, the device remained in operation until 1996.

Other installations followed in Livorno and Poppi, where a lightning rod was placed on the tower of the Castle of Counts Guidi in 1786. This installation served not only to protect the building but also to experimentally test the competing theories of Franklin and

Wilson regarding the shape of the rod's tip, pointed versus spherical. To test Coulomb's conclusion, Felice Fontana and Giovanni Fabbroni constructed a dual-tip conductor and conducted comparative observations.
Beccaria's instructions for constructing Franklin-style lightning rods were widely disseminated and adopted by scholars and enthusiasts alike, drawn to both their theoretical foundations and practical applications. Among them was the Piarist Girolamo Maria Fonda, who in 1769 succeeded Francesco Jacquier as chair of experimental physics at the "Roman Archiginnasio known as La Sapienza". Following a lightning strike on the dome of the church of Sant'Ivo alla Sapienza on 17 June 1770, Fonda contributed to the design of a lightning rod that was not only effective but also respectful of the architectural harmony envisioned by Borromini: "I would like the uniformity, spirit, and liveliness of Boromini's thought to be preserved" (Fonda, 1770). Two years after equipping the Observatory of the Roman College with a lightning rod, the astronomer Giuseppe Calandrelli was commissioned in 1789 to design and install protective systems for the Quirinal Palace and the church of Castel Gandolfo. These interventions signal a growing acceptance of electrical safety measures within religious and political institutions in central Italy (Calandrelli, 1789).

Electrical Experiments in Naples

Amid the vibrant intellectual landscape of 18th-century Naples, few figures rivaled the influence of Sir William Hamilton, British envoy extraordinary to the Bourbon court from 1764 to 1800 and a central figure in the city's political and cultural life. His contributions were instrumental in advancing the study and practical understanding of electrical science. Hamilton's tenure was also marked by a deep engagement with the natural world, particularly the volcanic phenomena of Vesuvius and Etna. This culminated in the publication of his influential work *Observations on Mount Vesuvius, Mount Etna, and other Volcanos*, which enriched contemporary scientific discourse and positioned Naples as a nexus of Enlightenment-era inquiry. Between 1772 and 1773, Hamilton guided the young Swiss Alpine expert Horace-Bénédict de Saussure up Vesuvius during his stay in Naples. In return, de Saussure later offered Hamilton a sublime experience: a tour of Chamonix in July 1776. Moreover, de Saussure shared news of Hamilton's electrical experiments with Franklin and conveyed Hamilton's volcanic theory, arguing that the entire Bay of Naples, from the sea to the Apennines, had been thrust up from the seabed by subterranean fires. In Hamilton's view, this region was not merely the site of volcanic destruction, but itself a creation of volcanic power. A passionate connoisseur of Greek vases as well as Etruscan and Roman antiquities, William Hamilton actively promoted the diffusion of aesthetic knowledge and helped popularize the neoclassical taste that defined the era. Many of his prized pieces were later acquired by the British Museum, substantially enriching its classical collections. During his Italian journey in 1787, Johann Wolfgang von Goethe paid a visit to Hamilton and was deeply struck by the ambassador's remarkable trove of antiquities and his magnetic intellectual presence. In his travel writings, Goethe lauded Hamilton's pioneering studies of volcanic activity and described his vase collection as among the finest in Europe (Darley, 2011, pp. 64-95).
The fascination of Hamilton with electricity, then an emerging field of study, was closely tied to his interest in volcanic phenomena, particularly the lightning associated with eruptions. In 1773, he acquired a Ramsden telescope to observe, from Naples, the violent ejections of stones and molten lava from the crater of Vesuvius. He also commissioned an electrical machine built by Edward Nairne, crafted according to specifications originally

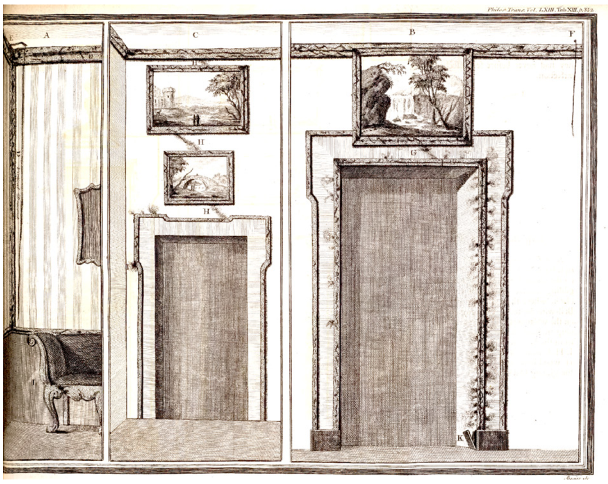
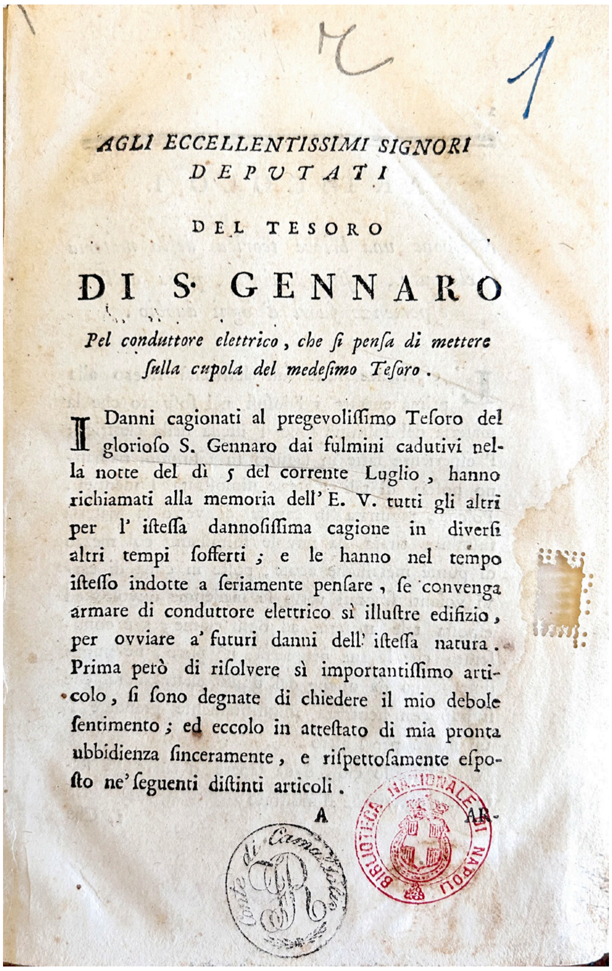


Figure 5: Lightning damage at Tinley's residence in Naples, as documented by William Hamilton. Credit: Royal Society.

proposed by Benjamin Franklin. The device was capable of producing sparks visible from several centimeters away, and emitted a "torrent of divergent light" from its conductor. Described by Hamilton as "the wonder of this country", the machine was employed in public and educational demonstrations, helping to foster scientific awareness and culture throughout Neapolitan society (Hamilton, 1773).

In parallel, Naples was home to a vibrant group of local scholars. Giovanni Maria Della Torre, a Somascan priest and a central figure in 18th-century Italian science, was among the first to replicate and comment on the experiments of Franklin, Gray, Du Fay, and other pioneers of electrical physics (Baldini, 1989). He collaborated with Felice Sabatelli, professor of astronomy, Vito Caravelli, mathematician, and the remarkable Maria Angela Ardinghelli, whom Lalande described as "the foremost among the illustrious women devoted to science in the beautiful country" (Vitrioli, 1874; Bertucci, 2013). Experiments were conducted in the *Bibliotheca Spinella*, housed within the palace of Prince Ferdinando Spinelli di Tarsia, which had been transformed into a genuine scientific laboratory. There, Peter Johann Windler, a traveling Saxon demonstrator who had



AGLI ECCELLENTISSIMI SIGNORI
DEPUTATI
DEL TESORO
DI S. GENNARO
Pel conduttore elettrico, che ſi penſa di mettere ſulla cupola del medeſimo Teſoro.

I Danni cagionati al pregevoliſſimo Teſoro del glorioſo S. Gennaro dai fulmini cadutivi nella notte del dì 5 del corrente Luglio, hanno richiamati alla memoria dell'E. V. tutti gli altri per l'isteſſa dannoſiſſima cagione in diverſi altri tempi ſofferti; e le hanno nel tempo isteſſo indotte a ſeriamente penſare, ſe convenga armare di conduttore elettrico sì illuſtre edifizio, per ovviare a' futuri danni dell'isteſſa natura. Prima però di riſolvere sì importantiſſimo articolo, ſi ſono degnate di chiedere il mio debole ſentimento; ed eccolo in atteſtato di mia pronta ubbidienza ſinceramente, e riſpettoſamente eſpoſto ne' ſeguenti diſtinti articoli.

A AR-

Figure 6: Frontispiece of the letter by Vito Caravelli. Credit: National Library of Naples.

previously exhibited his apparatus in Rome, impressing audiences with spectacular electrical displays in the dark, conducted experiments on electrical phenomena that similarly captivated the Neapolitan public. His demonstrations, marked by dramatic sparks and shocks, drew considerable interest from local scholars. Windler's notes culminated in the publication of *Tentamina de causa electricitatis* in 1747, which included trials conducted using an electrical machine designed by the prince himself, clear evidence of the direct involvement of Neapolitan nobility in scientific research. This electrical machine (Fig. 4) served both as a marvel for entertaining the prince's guests and as a valuable instrument for academicians, who employed it to elevate their standing within the broader landscape of

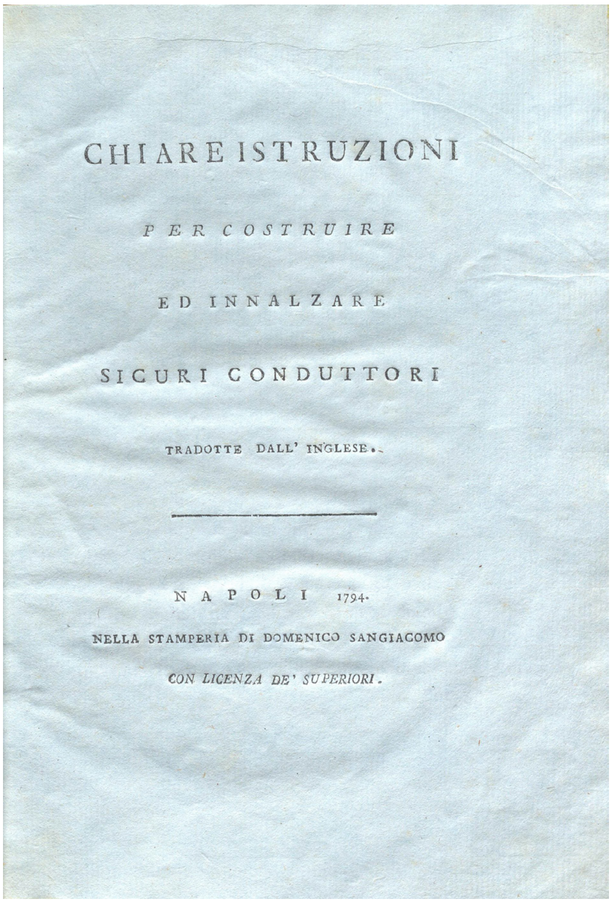
Neapolitan scientific culture (Bertucci, 2013).
In the second edition of *Scienza della natura generale*, Della Torre devoted extensive attention to electricity, describing its properties, the atmospheric conditions favorable to its manifestation, and the dynamics of attraction and repulsion between electrified bodies. He examined the electrical machines of Guericke, Hawksbee, and Musschenbroek, referencing the experiments of Windler and Mattia Boze. During public demonstrations, he observed that black silk was attracted more readily than white, and that humidity diminished electrical responsiveness, insights that presciently underscored the importance of material properties and environmental conditions (Della Torre, 1777, pp. 295-338).
This experimental environment also benefited from the contributions of Niccolò Bammacaro, professor of philosophy at the University of Naples and author of *Tentamen de vi electrica ejusque phaenomenis* (1748). In this work, Bammacaro challenged Jean-Antoine Nollet's double-fluid theory, dismissing the notion of "affluent matter" as an unverifiable hypothesis. Instead, he proposed a model based solely on "effluent matter", which compressed the surrounding air to form a "vortex aëreus", an electrical atmosphere exerting mechanical pressure that pushed bodies toward the electrified source, offering a physical alternative to fluid-based explanations. Although Nollet contested the theory for lacking vacuum-based experimentation, Bammacaro's work stands as an original Italian contribution to the interpretation of electrical phenomena.
Finally, Giuseppe Saverio Poli, professor of experimental physics at the University of Naples, played a pivotal role in consolidating the teaching of electrical theories. As early as 1772, he published *La formazione del tuono, della folgore e di varie altre meteore spiegata giusta le idee del Signor Franklin*, a treatise that drew upon Franklin's theories to explain atmospheric phenomena, reflecting the integration of experimental science into contemporary educational practices. Over the following two years, Poli published *Riflessioni intorno agli effetti di alcuni fulmini* (1773) and *Continuazione delle riflessioni intorno agli effetti di alcuni fulmini* (1774), in which he critiques a purely theoretical and book-centered approach to science, advocating instead for a method of inquiry grounded in inductive reasoning and direct observation. In the 1773 volume, Poli also documented experiments conducted in the presence of several distinguished figures, among them William Hamilton; Simone Cavalli, Resident of the Republic of Venice; Prince Casimiro Pignatelli d'Egmont; and Ascanio Filomarino, Duke della Torre. In his *Elementi di fisica sperimentale* (1781-1783), Poli devoted extensive sections to electricity and lightning, noting the presence of a Dollond electrical machine belonging to Giovanni Vivenzio, Archiater and Royal Protomedicus. The instrument formed part of a scientific collection used for public demonstrations and experimental instruction. Poli's method, grounded in direct observation and empirical practice, significantly strengthened the teaching of natural sciences in the Kingdom of Naples and promoted a systematic, functional approach to atmospheric physics (Schettino, 2001).

Chronicles of Lightning in Naples

Across the centuries, Naples has endured atmospheric phenomena of extraordinary violence, including lightning strikes in densely populated quarters of the city. These episodes, vividly chronicled by clerics, historians, and scholars alike, offer a valuable lens through which to interpret the evolving worldviews within the Kingdom of Naples. Interpretations, layered and diverse, oscillate between faith and empiricism, miracle and measurement.
One of the earliest recorded lightning strikes in Naples occurred on 29 September 1600, at the Church of San Paolo, built atop the ruins of the ancient temple of the Dioscuri in the agora of Neapolis. Tommaso Costo, Secretary

Figure 7: Palace Doria d'Angri in Naples, with a lightning rod visible atop the building. Depicted in *Via Toledo dalla piazza dello Spirito Santo*, an 1837 painting by Gaetano Gigante. The same lightning rod is more clearly visible above the Italian flag in the *Ingresso di Garibaldi a Napoli*, a hand-colored ink drawing by Martino Francesco Wenzel, dated 1860 and housed at the Municipal Museum of Castel Nuovo. Credit: Museum of San Martino.

of the High Court of the Admiralty of the Kingdom of Naples, recounts that the bolt "caused great damage, particularly breaking the bell tower, the tribune and part of the choir above the main altar" (Costo, 1613, p. 159). Mere weeks later, on 25 November, chronicler Domenico Parrino notes that another bolt struck the Basilica, again targeting the bell tower and choir with severe destruction. That winter proved especially harsh: by January 1601, torrential rains and violent winds sank a galley, six ships, and numerous smaller vessels along the stretch between Naples' port and the Gulf of Salerno. On 30 November of that same year, lightning struck the Convent of the Cross of the Reformed Fathers of Saint Francis, located on the site that would later become Palazzo Salerno in Piazza del Plebiscito. The bolt tore through the bell tower and entered a chapel during a Eucharistic celebration. The officiating priest fell supine to the ground, unconscious. Upon recovering unharmed, "he looked into the chalice containing the consecrated blood and found it, as a result of the strike, to be of a bruised, livid



CHIARE ISTRUZIONI

PER COSTRUIRE

ED INNALZARE

SICURI CONDUTTORI

TRADOTTE DALL' INGLESE.

NAPOLI 1794.

NELLA STAMPERIA DI DOMENICO SANGIACOMO

CON LICENZA DE' SUPERIORI.

Figure 8: Frontispiece of the book translated by Felice Sabatelli. Credit: Astronomical Observatory of Capodimonte.

color" (Costo, 1613, pp. 162–163), so he replaced it to continue the celebration. Parrino later reported a different version, in which the officiant observed a strange discoloration in the consecrated hosts: "he found them livid and changed in color" (Parrino, 1730, p. 9), and promptly replaced them. The Viceroy, Count of Lemos, witnessed the event and personally funded the restoration of the bell tower and the damage caused to the church. As storms and illness continued to afflict the city, the Viceroy ordered a solemn procession carrying the relics of Naples' seven patron saints, including Saint Januarius with his miraculous blood. In the days that followed, the weather cleared, widely interpreted as a sign of divine intervention (Costo, 1613, pp. 162–163; Parrino, 1730, p. 9).

Years later, on 30 November 1656, a "terrible lightning bolt" devastated the Basilica of Santa Maria del Carmine, destroying the bell tower, roof, and choir, and collapsing the attic. Reconstruction was made possible through the generosity of the Neapolitans, among them Viceroy García de Avellaneda, Count of Castrillo, and Domenico Del Giudice, Prince of Cellammare. The phenomenon returned on 19 September 1728 and once more on 27 September 1745, when another lightning bolt struck the bell tower, tearing off massive blocks of marble and piperno, which crashed down onto the roof. Sweeping through the church, the bolt reportedly ruined both organs. Yet, in what was deemed miraculous and attributed to the protection of Mother Mary, the choir monks present remained unharmed. Despite repairs, the bell tower again succumbed to lightning in 1762 (Filangieri, 1885, pp. 176-180).

Another extraordinary episode unfolded on 30 June 1714 at the Monastery of Santa Maria della Provvidenza, nestled in Largo dei Miracoli within Naples' Sanità district. As nearly fifty nuns chanted canonical praises, a bolt of lightning struck with terrifying force, piercing both the bell tower and the choir. According to Serafino Montorio (1715, p. 74), the discharge surged through the entire complex, even reaching the distant washhouse, yet astonishingly, no one was harmed. The nuns, attributing their preservation to the Virgin Mary, expressed their gratitude with a solemn procession, carrying her miraculous image through the streets.

With the rise of scientific culture in the eighteenth century, the understanding of lightning underwent a profound transformation. No longer viewed solely through theological or symbolic frameworks, atmospheric electricity began to be examined through empirical observation and experimental inquiry. William Hamilton, in a letter to Matthew Maty, secretary of the Royal Society, precisely described an episode that occurred on 15 March 1773 at the Neapolitan residence of Lord John Tylney:

> "*On Monday last, about half past ten at night, I had the satisfaction of being one, of many witnesses, to several curious phenomena, occasioned by the lightning having fallen on Lord Tylney's house, in this city*". (Hamilton, 1773, p. 324)

A discharge passed through nine rooms, damaging gilded surfaces, bell mechanisms, and metal furnishings, without injuring any of the 500 guests present.

> "*A Polish prince, who was playing cards, heard the report (which he took for a pistol), and feeling himself struck, jumped up, and, clapping his hand to his sword, assumed a posture of defence. I was sitting at a card-table, and conversing with Monsieur de Saussure, Professor of Natural History at Geneva… I thought an Indian cracker had been fired, while Monsieur de Saussure believed it was the report of a pistol; but amid the confused cries and noises, we heard a voice exclaiming,* Un fulmine, un fulmine! *We began to examine the gallery in which we were*". (Hamilton, 1773, pp. 324-325)

Hamilton analyzed the conductive path of the lightning along frames, gilded surfaces, and metallic materials, replicated the phenomenon in the laboratory, and confirmed Franklin's theories (Fig. 5). His observations laid the groundwork for new architectural strategies for electrical protection (Hamilton, 1773).

Complementing Hamilton's efforts, de Saussure provided a contemporaneous account of the strike. He and Hamilton examined the house and terrace the following morning, driven by what de Saussure described as "the spirit of observation and the lights", in an effort to trace the lightning's path. De Saussure concluded that the fulminant charge entered through the gutters of the rooftop terrace, traveled through the house, exited largely through the well, and filtered vertically through the walls. His detailed report echoed Hamilton's findings and culminated in a pointed recommendation: "May this event, which seems to be a warning intended to open the eyes to the use of conductors, serve as an example from one of the most enlightened nations of Europe, making the use of a conductor both so easy and so safe universal" (De Saussure, 1773).

In June 1774, Gaetano de Bottis, professor at the Royal Academy of Nunziatella, offered one of the most vivid first-person accounts of a lightning strike near the Monastery of Santa Chiara. The bolt hit the Palace Invitti of Princes of Conca, generating an intense flame and a vibrating fireball, accompanied by tremors, shattered glass, black smoke, and a pungent smell of sulfur and bitumen. De Bottis wrote:

> "I was in my small study, conversing with a friend precisely about the strange and terrible effects of lightning... I saw the outside air completely enveloped in a dense and vivid flame[1], and it seemed to me that within it appeared a fireball which, by my eye's judgment, had a diameter of about three finger-widths and was radiating rays in every direction[2]. At that very moment, the floor beneath me shook and the windowpanes trembled forcefully; I also distinctly heard many panes of glass shattering violently on the side of the aforementioned palace… Immediately afterward, I heard loud and anguished cries in the streets.
>
> [1] *It took a while to die, since I saw it still burning even after I got up from where I'd been sitting.*
>
> [2] *A similar fireball was seen in the sky above the aforementioned square, which exploded violently, causing two people passing by to fall face down to the ground and become stunned. At the same time, others were observed atop the battlements of a small temple next to the Church of San Domenico Maggiore. Such fireballs have appeared on other occasions, and some have been seen as large as the apparent size of the Moon, and even larger, whose explosions have caused extremely serious destruction, as is well known from Natural History*. (De Bottis, 1774, pp. VII-VIII)
>
> The account, rich in emotional engagement and acute phenomenological observation, culminates in a reflection on the distribution of "electrical matter." De Bottis concluded by affirming the effectiveness of metallic conductors for building protection, fully endorsing Franklin's theories". (De Bottis, 1774)

This convergence of wonder and empirical thought soon gave rise to institutional action. After the lightning strike that damaged the Treasury dome on 5 July 1786, the Deputation of San Gennaro, custodians of the saint's relics and treasure, considered equipping the structure with a lightning conductor to prevent future harm. They commissioned mathematician Vito Caravelli, who proposed the installation of a lightning rod. He presented his plan in a rare pamphlet dated 15 July 1786, *Agli eccellentissimi signori deputati del tesoro di S. Gennaro. Pel conduttore elettrico, che si pensa di mettere sulla cupola del medesimo Tesoro* (Fig. 6). In it, the mathematician outlined the principles of electrical charge and the behavior of lightning, emphasizing how conductive materials could safely divert strikes away from buildings. Caravelli strongly condemned the widespread negligence surrounding lightning protection, even in buildings that sheltered human lives and irreplaceable assets. Addressing prevalent fears that lightning rods might attract strikes, he argued such views stemmed from ignorance of electrical theory. He explained that, when properly constructed, using proportional thickness and uninterrupted pathways, metal conductors allowed lightning to pass harmlessly into the ground. As a final point, Caravelli appealed not just to theoretical understanding but to practical evidence: by that time, countless buildings in Europe and America had already adopted lightning conductors, and none, if built according to scientific principles, had suffered lightning damage in years. He concluded, "Opposition to lightning rods contradicts both theory and experience".

Around the same time, Giuseppe Marzucco, professor of Mathematics at the University of Naples, also endorsed the installation of a lightning conductor. In his *Parere scritto alla Eccellentissima deputazione del Tesoro di S. Gennaro, intorno alla spranga elettrica* (1786), he claimed to have advocated for the idea for over twelve years. Echoing Caravelli's empirical approach, Marzucco affirmed that "anyone well-versed in true physics immediately recognizes when a truth is legitimately derived from experience."

Yet despite scientific support, within a year, another lightning strike darkened the dome, blackened its walls, and stripped gilded ornament from its surface. Restoration efforts ignited fierce debate. Antonio de Simone, the Chapel's official architect, insisted on preserving the original stucco proportions, while his collaborator Gaetano Barba advocated for an academic reinterpretation. Their disagreement prompted intervention from esteemed architects, including Luigi Vanvitelli, Antonio de Sio, and Pompeo Schiantarelli, who ultimately favored De Simone's measured fidelity to the building's historical identity (Croce, 1904).

Despite the combined rigor of Caravelli's and Marzucco's proposals, and the philosophical momentum they embodied, there is no evidence that the dome was ever equipped with a lightning rod.

The episode involving the dome of San Gennaro reflects a broader Enlightenment paradox: science marked the path forward, yet progress remained hostage to fear, tradition, and indecision. The narratives of Parrino, Montorio, and De Bottis, alongside the exhortations of Caravelli and Marzucco, trace an evolutionary arc in Naples' evolving relationship with lightning, spanning transcendent visions, miraculous interpretations, and culminating in scientific analysis.

Naples becomes a stage for cultural transformation. In its majestic destructiveness, lightning inscribes itself into the city's urban fabric, inviting a plurality of interpretations: from celestial messenger to measurable phenomenon, reflecting the ongoing evolution of modern thought. These testimonies preserve the memory of exceptional events and document how society sought to interpret and respond to the sudden blaze that erupted in the heart of the city.

"Chiare istruzioni": Historical Observations and Recommendations for Urban Architecture

Throughout the 18th century, the use of lightning rods gradually became established as a protective measure against damage caused by atmospheric discharges. Numerous documented events helped consolidate the effectiveness of these devices, among which the installation of a lightning rod on Saint Paul's Cathedral in London stands out. In 1764, after a lightning strike near the building, the Royal Society launched a comprehensive study to determine the most effective protection system. A distinguished committee, including John Canton, Edward Delaval, Benjamin Franklin, William Watson, and Benjamin Wilson, proposed a structure of iron bars to be installed on the dome, completed in 1769 (Bristol, 1769). Four years later, the cathedral sustained further damage due to lightning. Upon investigation, the committee found that the original installation instructions had not been properly followed. Despite this setback, the lightning rod remained in place until 1899, affirming the soundness of the principle on which it was founded.

Another incident demonstrating the lightning rod's protective power occurred in the port of Quebec in 1773 and was recorded in *Philosophical transactions*. The event is described in a letter from Captain Richard Nairne, whose account offers compelling evidence of the device's effectiveness. Below is an excerpt from his correspondence describing the phenomenon:

> *"I shall make every observation I can, for the good of electricity, and the satisfaction of my friend Mr. Henley. I put up a longer topgallant mast, the day I arrived at Quebeck. The conductor, by this means, became too short; and my mate still let it hang, without making any addition to it. They had a severe thunder storm that night; but think how pleased I was to find, that, from the wetness of the ship's sides, the elec-*

tricity passed into the water, without the least injury to the ship; but the spark on the point of the conductor, which was very sharp, was so lucid, that my people were very much frightned". (Henly, 1774, p. 139)

The benefit of the lightning rod is further demonstrated by Lieutenant Fairlamb's report on St. Michael's Church in Charles Town, South Carolina. Historically, the church suffered lightning strikes and damage every two or three years, but since the installation of a pointed conductor, it has remained untouched for fourteen consecutive years (Henly, 1774, p. 139).

In February 1778, Naples also entered the history of electrical protection with the installation of its first lightning rod. The initiative, promoted by Duke Ascanio Filomarino and Giovanni Carpintero, was enthusiastically received by the Italian press. The *Gazzetta universale* reported the event in a style that blended scientific spirit with worldly flair:

"Fashions multiply quickly, philosophical inventions slowly, but when they acquire the character of fashion, they too spread rapidly. Here is the first metal conductor erected in Naples under the direction of Don Ascanio Filomarino, Duke of Cutrofiano, a gentleman who combines science with practical skill and the refinement of mechanical and mathematical craftsmanship. Mr. Don Giovanni Carpentieri, brother of the Marquise Goizuetta, is the one who had it installed on his residence. Soon, the example will be followed in both private and public buildings".

To magnify the event, the newspaper concluded the report with Latin verses celebrating the "Ferrea cuspis":

"Ferrea haec cuspis
In summa trabe posita
Tonantem Jovem lacessit
Quippe quae ejus ignes
Per aethereas sedes discurrentes
Absumit devorat
Per que longissimum brachium dissipat
Altero mutilo relicto
Efficacitatis indice ac teste
Primum Neapoli dedicata est
A Johanne Carpintero
Postridie nox Februar
Anno MDCCLXXVIII
Ascanio Philomarino Duce". (*Napoli 5 Maggio*, 1778)

This lightning rod was installed on the residence of Giovanni Carpintero, brother of Isidora, wife of Juan Asensio de Goyzueta, the Secretary of State and Affairs, who resided in the palace on Via Correra. A specific testimony to the effectiveness of this installation will be examined later. The enthusiastic tone of the *Gazzetta universale* suggests that the lightning rod, originally conceived as a technical device, was quickly gaining symbolic and cultural resonance, transforming into a "useful model" destined for urban diffusion.

A prominent figure in Naples' scientific landscape, Ascanio Filomarino had already distinguished himself for his expertise in mathematics and natural history. As Gentleman of the Chamber to King Ferdinand IV, he authored studies on Vesuvius and collected and cataloged an extensive array of minerals and geological illustrations. His residence in Largo San Giovanni Maggiore, now palazzo Giusso, functioned as a true domestic laboratory, hosting cultural gatherings, scientific debates, and technical experiments, thanks to a cabinet equipped with instruments for detecting seismic movements. Filomarino's intellectual journey came to a tragic end in January 1799, during the unrest preceding the Neapolitan revolution. With the Bourbon court fleeing to Sicily and power handed to the *lazzari*, the duke was accused of collaborating with the Frenchs after a letter was intercepted by his hairdresser, Giuseppe Maimone. On 18 January, his palace was stormed: the library destroyed, artworks looted, scientific instruments ravaged. Ascanio and his brother Clemente were chained, taken to Santa Maria in Porto Salvo, executed by firing squad, and burned inside barrels filled with tar. Their brutal death caused deep shock, depriving Naples of one of its most refined and respected minds (Iermano, 1997).

In a sonnet dedicated to his brother, celebrated as "honor of Italy and light of the Neapolitan land", Clemente Filomarino poetically captured his fascination with electrical studies and experimentation:

> "[Love]
> *flew to your lodging, O Ascanius, and by the thousands*
> *saw, through the glass wheel spinning round,*
> *swift electric sparks burst forth"*. (Filomarino, 1789, p. 23)

Filomarino's pioneering example did not remain isolated. In the following decades, the culture of the lightning rod gradually extended to other prestigious buildings in the Bourbon capital. Among the earliest notable installations was the residence of William Hamilton at Palazzo Sessa, which also served as the British embassy. Situated at the foot of Pizzofalcone in the distinguished San Ferdinando neighborhood, near today's Piazza dei Martiri, the palace, like other noble residences built between the late 17th and early 18th centuries, enjoyed a splendid view of the Gulf of Naples.

The lightning rod was likely installed in the balcony room on the upper floor, which offers a sweeping panorama of the gulf. Hamilton himself had designed and adorned the room with remarkable flair and ingenuity. It was his cherished retreat, a place for reading, reflection, and quiet contemplation. Even Goethe was captivated by the view, writing in his *Tagebuch*:

> *"the view from the corner room is perhaps unique. Below you is the sea, with a view of Capri; Posilippo on the right, with the promenade of Villa Real… and beyond it the coast stretching from Sorrento to Cape Minerva. Another prospect equal to this is scarcely to be found in Europe"*. (Goethe, 1902, p. 334)

Hamilton's fascination with scientific instrumentation and environmental protection is echoed in Amanda Elyot's novel, where Hamilton proudly references the lightning rod:

> *"We stepped out of the library into a corridor, where Sir William proudly pointed out the water closet. The plumbing in the Palazzo Sessa was the most advanced to be had, and owing to his studies of the sciences and the elements, he had also caused a lightning rod to be installed on the roof. 'Ladies, it gives me pleasure to say that you will be residing in the safest house in Naples' "*. (Elyot, 2007)

It is likely that Hamilton's other residences: Villa Emma in Posillipo, where he spent summers enjoying sea dives, and Villa Angelica in Torre del Greco, from which he made his first observations of the 1766 eruption of Vesuvius, were also equipped with lightning rods, demonstrating his commitment to scientific advancement and his proactive approach to public safety.

Other noteworthy installations included the palace of Francesco d'Aquino, Prince of Caramanico, on Via Medina, and the palace of Prince Doria d'Angri in Largo Santo Spirito, now Piazza Sette Settembre, where the lightning rod was meticulously designed by the architect Schiantarelli.

Such interventions reflect the growing integration of scientific progress into Naples' urban context and the nobility's desire to combine technical modernity with social prestige. The lightning rod thus became a visible emblem of a city that chose to confront environmental risk with knowledge and ingenuity, laying the foundation for a new culture of urban safety.

In 1794, facilitated through the combined initiative and patronage of William Hamilton, the treatise *Chiare istruzioni per costruire ed innalzare sicuri conduttori* was published in Naples, translated from english by Felice Sabatelli and printed by Domenico Sangiacomo (Fig. 8). The volume, dedicated to Princess Doria d'Angri (possibly Giovanna Pappacoda, widow of Giovanni Carlo, or Teresa Doria del Carretto Sforza Visconti, wife of Marcantonio Doria, 8th Prince d'Angri), who had installed a "well-designed conductor" after a traumatic atmospheric event at her residence, marked a pivotal moment in the dissemination of lightning rod technology in urban settings.

The publication presents an intriguing chronological anomaly: Sabatelli died in 1788, meaning the Italian edition must have been prepared at least six years before its actual printing. At present, the volume is available in Italy solely through the book collection of the Astronomical Observatory of Capodimonte (STOR. ANT. Meteor. Geof. Geol. I016), while copies of the same edition are preserved at the Harvard Library (Houghton Library GEN *IC7 Sa134 794c), the Smithsonian Libraries and Archives (QC611 .C53 1794), and Yale University's Sterling Memorial Library (Franklin-230 421 1794).

Although the treatise was tentatively attributed to Hamilton, following Sangiacomo's editorial note: "some years ago, the following pamphlet in English was given to me by Sir William Hamilton, a gentleman of great expertise in such matters" (Sangiacomo, 1794), its true author was John Simmons, an English physician and pharmacist with a distinctly empirical interest in electrical phenomena. The original work of Simmons, *Plain directions for constructing and erecting safe conductors*, appeared in 1775. It was published as an appendix to the volume *An essay on the cause of lightning, and the manner by which thunder-clouds become possessed of their electricity, deduced from known facts and properties of that matter*, in which he presented the physical theory of lightning based on natural observations.

Little is known about Simmons's life beyond his medical practice in Chatham and his charitable engagements. Born around 1708 in Luddenham, Kent, and deceased in Faversham in 1794, Simmons was one of the self-taught popularizers who helped democratize science, figures who translated complex theories into accessible, actionable knowledge (Timpson, 1859, p. 436; *The Kentish register*… 1794, p. 75). His treatise, dedicated to Hamilton as a tribute to a leading figure in European naturalism, reflects a pragmatic ethos: it avoids speculative theory and instead offers clear, technical guidance for constructing lightning rods. Simmons builds on the theories of Franklin, Du Fay, and Watson, yet remains firmly committed to an empirical framework. He proposes that electrical fluid accumulates in clouds by ascending from the earth, and that discharges invariably proceed downward, never in reverse.

Simmons's recommendations are precise: conductors should be made of copper or iron, sharply pointed, uninterrupted, and placed at the highest point of a building. They must be grounded directly into moist soil or, ideally, into subterranean water. Crucially, he refutes the widespread belief that lightning rods "attract" lightning; rather, they intercept and safely dissipate electrical discharges already in motion.

The treatise was born from a request in May 1774, when a guest invited Simmons to conduct electrical experiments at his home in Chatham. Encouraged by the enthusiastic response of his "ingenious Friends", he published the text and appended a "very necessary" section designed to make the device intelligible to the general public. In doing so, Simmons helped transform lightning protection from elite science into shared civic knowledge (Simmons, 1775).

The Italian translation, curated by Sabatelli, an astronomer, Newtonian philosopher, and active participant in the experiments at *Accademia Spinella*, was both faithful and enriched with two original notes from the translator.

According to Sangiacomo's introduction, the installation of the first lightning rod in Naples, led by the Duke della Torre and Giovanni Carpintero, was validated just one month later, on 3 March 1778. During a violent storm, witnesses observed a fireball descend onto the tip of the lightning rod on Carpintero's residence and vanish harmlessly into the moist ground. This public and visible event offered compelling proof of the device's efficacy.

Yet despite such evidence, adoption in Naples remained limited. Beyond Carpintero's residence, only a few installations are recorded, including those at the residences of William Hamilton, the Princess of Caramanico, and Prince Doria d'Angri. This hesitation stemmed largely from a lingering misconception: that lightning rods attract, rather than deflect, electrical discharges.

To counter this, Sangiacomo published the treatise with a clear mission: to make "its reading common in Naples, hoping that the use of the aforementioned conductors, already long adopted in England, Holland, Germany, France, Lombardy, and Tuscany, might likewise gain traction among us. This practice was especially vital in our region, where lightning frequently strikes and often inflicts serious damage" (Sangiacomo, 1794).

The editor emphasized that the device does not lure lightning but intercepts it during descent, ensuring safe dissipation. Moreover, Naples' subsoil, rich in aqueous bodies and deep aquifer networks, was ideal for grounding electrical fluid, unlike neighboring volcanic zones, which required deeper perforations to reach conductive layers (Sangiacomo, 1794).

In light of these observations, it is hoped that the adoption of lightning rods will become standard practice, free from superstition and grounded in scientific evidence. As the publisher writes in the introduction:

> *"I flatter myself that, by dispelling ancient prejudices, the reading of this modest work may help render the highly beneficial use of conductors common among us".*

This statement encapsulates the treatise's broader ambition: to promote a culture of urban electrical safety, rooted in scientific clarity, civic responsibility, and architectural foresight. In this perspective, Naples becomes an intellectual laboratory, where Enlightenment ideals meet architectural pragmatism. Lightning is reimagined: from divine wrath to governable force, from invisible peril to a physical principle mastered through lucid design.

Yet despite this scientific and social momentum, the ancient "lantern of the pier" in Naples, originally erected in 1487 by the king Ferrante d'Aragona and rebuilt multiple times after fires caused by disastrous lightning strikes, was only protected in 1843, when "the expert hand of Melloni lowered an electrical conductor to the ground, shielding it from the ancient calamity" (C[apocci], 1843, p. 119).

Conclusions

The history of lightning, retraced through philosophical, religious, scientific, and urban sources, reveals a long intellectual trajectory spanning millennia of observation, interpretation, and experimentation. From Thales' amber to Hawksbee's globes, from the thunderbolts of Etruscan gods to the laboratory of Palazzo Tarsia, lightning has marked the unstable boundary between terror and prediction, the unknown and knowledge.

Within this historical arc, Naples emerges as a paradigmatic case. Here, the celestial flash is more than a natural occurrence; it is entwined with epistemic ambition, technical innovation, and the urgent imperative of urban protection. Naples answered the challenge of atmospheric discharges with the intellectual rigor of Della Torre, Caravelli, and Poli; the diplomatic finesse of Hamilton; the visionary foresight of Filomarino; and the empirical engagement of Sangiacomo. The city did not merely endure lightning as an event: it interpreted it, replicated it, measured it, and ultimately mastered it.

In this context, the lightning rod transcends its technological function, emerging as a tangible emblem of cultural transformation. Once regarded with suspicion and fear, the lightning rod evolved into a scientifically sanctioned instrument, embodying a transformation in urban consciousness, one that reimagined risk as responsibility and transmuted danger into design. Yet the reluctance and fears that accompanied its adoption reveal that the culture of safety is, at its core, a continuous negotiation between belief, habit, and scientific reason.

The concept of *South-risk* thus reveals its full ambivalence: the South as a place exposed, vulnerable, and subject to intense natural phenomena; but also as a fertile ground for rational, systemic, and design-driven responses, a vision that may be defined as *South-safety*. Naples, with its historical and scientific stratification, offers a unique interpretive lens: a city that has looked to the sky not only with fear, but with method, transforming lightning from a divine threat into an opportunity for knowledge and architectural regeneration.

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Amphibian conservation through captive breeding: the case of the harlequin toads (Anura, Bufonidae, *Atelopus*)

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Abstract

Amphibians are the most threatened class of terrestrial vertebrates: approximately 41% of species are on the brink of extinction or in decline due to habitat loss, climate change, and emerging diseases. Projects involving ex situ and in situ conservation are crucial to preserving the integrity and future of many amphibian populations and species. This paper reviews some of the conservation initiatives developed for species in the genus *Atelopus* (Amphibia, Bufonidae). It also focuses particularly on ex situ conservation activities carried out for *A. balios*, providing an overview of the results.

Keywords. Amphibian decline, *Atelopus*, harlequin toads, ex situ conservation projects.

Riassunto

Gli anfibi sono attualmente la classe di vertebrati terrestri più in pericolo. Circa il 41% delle specie è sull'orlo dell'estinzione o in forte declino a causa della perdita e dell'alterazione degli habitat, del cambiamento climatico e di patologie emergenti. Pertanto, i progetti di conservazione ex situ e in situ sono di fondamentale importanza per la preservazione dell'integrità e il futuro delle popolazioni di molte specie. Le strategie finora adottate sono varie e in questa review discutiamo di alcune delle modalità ed iniziative di conservazione tramite allevamento in cattività, adottate per le specie di *Atelopus* (Amphibia, Bufonidae) a rischio. In particolare, questo lavoro fornisce anche una sintesi delle attività di conservazione ex situ messe in atto per *A. balios*.

Parole chiave. Declino globale degli anfibi, *Atelopus*, rospi arlecchino, progetti di conservazione ex situ

Introduction

According to the Second Global Amphibian Assessment, around 41% of amphibian species worldwide are currently threatened with extinction (Luetdke et al., 2023). Indeed, amphibians are one of the vertebrate groups most affected by this decline and are considered a key indicator of the ongoing global biodiversity crisis. Major threats include habitat destruction and fragmentation caused by human activities, pollution from agricultural and industrial sources and the rapid spread of diseases such as chytridiomycosis, which is caused by the fungal pathogens, such as *Batrachochytrium dendrobatidis* (*Bd*) and *B. salamandrivorans* (*Bsal*) (Luetdke et al., 2023). These pressures have had a drastic effect on populations, resulting in local extinctions and severe disruption to ecosystems.

In this context, species belonging to the *Atelopus* genus (commonly known as "harlequin toads") were particularly affected: many *Atelopus* populations have suffered sharp declines in recent decades, with several species currently classified as Critically Endangered (CR) or Extinct in the Wild (EW) (Lötters et al., 2023). So far, it is clear that conservation efforts targeting these species therefore require urgent integration of in situ and ex situ strategies.

The current review aims to explore some of the key risks and threats affecting *Atelopus* species, and to provide a synthesis of the conservation measures and initiatives implemented at local and international levels. Emphasis has been given on ex situ conservation programmes, which have emerged as a crucial tool for preventing species extinction, particularly when natural populations can no longer be protected in their native habitats (Pavajeau et al., 2008). Particular attention has been given to actions involving captive breeding techniques developed for *A. balios*, shedding light on the challenges, advances and prospects of these approaches.

The harlequin frogs

The genus *Atelopus* is included within the Bufonidae family (true toads), despite their overall "frog-like" appearance. Their main morphological traits have often misled biologists regarding their phylogeny, since features such as brilliant skin colouration (the origin of the name "harlequin frogs") (fig. 1) and the presence of skin-produced toxins are widespread in several anuran families (e.g. Dendrobatidae, Mantellidae, Microhylidae and Phyllomedusidae). The 105 *Atelopus* species (at the 14 December 2025, https://amphibiaweb.org/) are characterised morphologically by small-to-medium body sizes (17–50 mm), smooth dorsal skin, a conspicuous absence of parotoid glands, well-developed interdigital webbing, the reduction of the first digit, lack of the middle ear in most of the species and vivid aposematic colouration correlated with the presence of skin alkaloids and bufadienolide toxins used for chemical defence (Lötters et al., 2011). The species are distributed in the forests of Central America (Panama) and South America (Colombia, Ecuador and Venezuela) (Amphibiaweb, 2025). The last IUCN report assessed 94 species of *Atelopus*, classifying 62 as Critically Endangered (CR), with 39 of these possibly already Extinct in the Wild (EW) (Lötters et al., 2023).

Threats affecting the harlequin toads

Anthropogenic activities often have a negative impact on global biodiversity, leading to habitat degradation and fragmentation, as well as the spread of emerging diseases

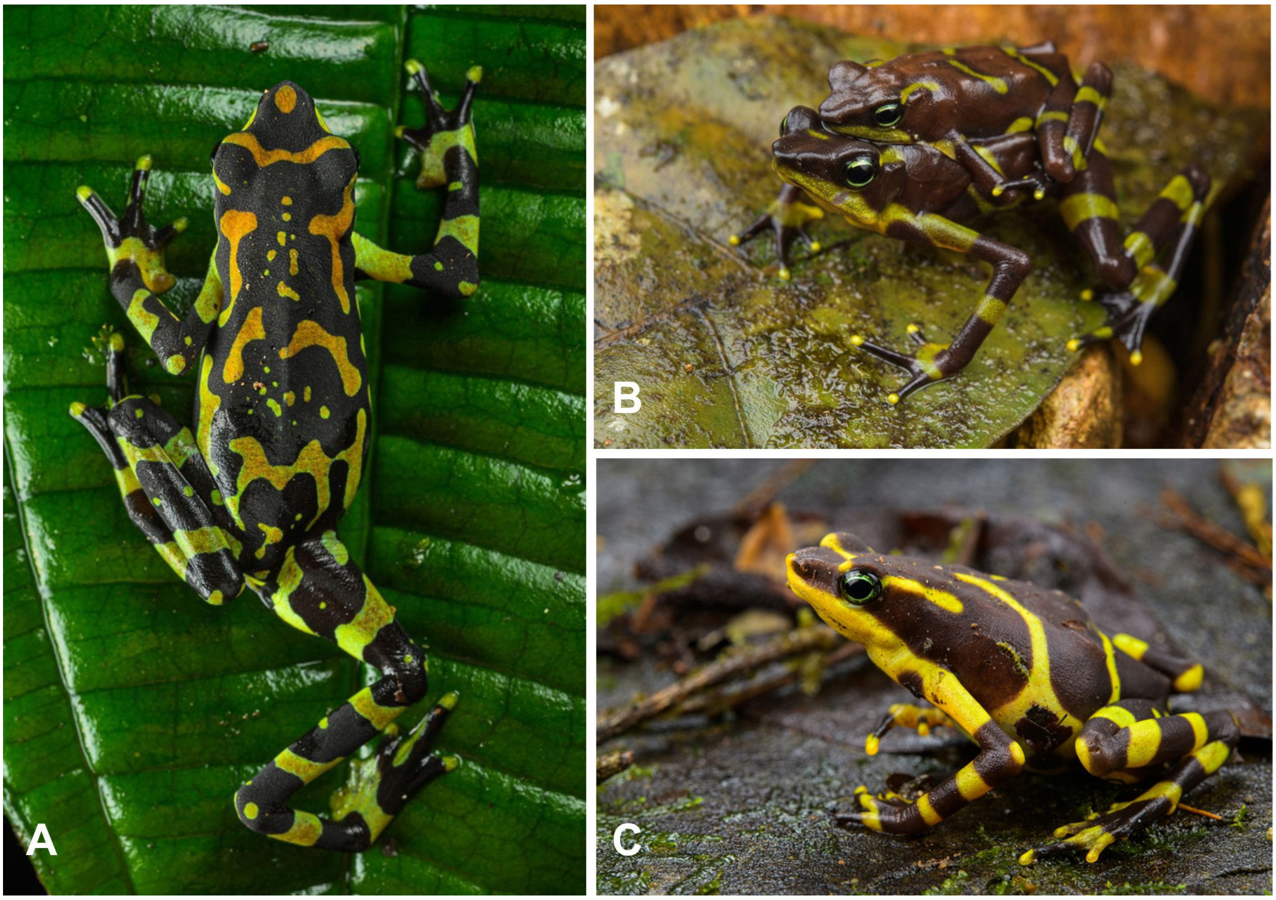

Figure 1: Variability within the genus *Atelopus*: (A) *Atelopus varius* "morph C", (B) *Atelopus limosus*, (C) *Atelopus glyphus.* (© Emanuele Biggi)

(Suriyamongkol et al., 2021; Rosas-Espinoza et al., 2022; Yu et al., 2022). These effects are particularly pronounced in sensitive organisms, such as amphibians, which are closely associated with humid environments and often lead double lives as aquatic tadpoles and terrestrial adults. According to the 2023 IUCN Red List, 91% of species belonging to the orders Anura, Urodela and Gymnophiona experienced a significant decline in their conservation status between 1980 and 2004. One of the most pressing threats is the spread of emerging diseases, such as chytridiomycosis, which is caused by two species of *Batrachochytrium: B. dendrobatidis and B. salamandrivorans* (Fisher et al., 2009), which are aquatic fungi belonging to the order Chytridiales. Both *Batrachochytrium* species likely originated in Asia and have since spread worldwide through human activities (Martel et al., 2014). These fungi have contributed to the decline of over 500 amphibian species, accounting for at least 6.5% of all described amphibian species (Scheele et al., 2019). Twenty-seven *Atelopus* species declined rapidly from 1984 to 2004; more than half of these had not been seen for a long period of time, and only 10 had stable populations.

Ex situ conservation: goals and opportunities

Ex situ conservation provides a vital safety net and a powerful tool for research, especially when in situ efforts are compromised or the species is difficult to study in its natural habitat. Ex situ conservation programs have been successfully conducted for several threatened amphibian species (i.e, Harris et al., 2022).

A major problem with studies focused on threatened amphibians is sampling. The elusive nature of some species, coupled with the loss of many ecological niches, can mislead or even prevent the collection of new data on presumed threatened species. Harlequin toads are a prime example of this.

Studies based on pathogen-induced mortality, infection rates and population recruitment rates demonstrate that these species have coexisted in endemic equilibrium with Bd for almost a decade (Ballestas et al., 2021). This highlights the importance of in situ research to improve our understanding of trends in anuran populations.

Captive breeding programmes are fundamental to establishing ex situ populations, particularly for highly endemic anurans that are threatened by diseases and human activities. In some cases, these programmes represent "the last hope" of saving the species from extinction. It is also important to note that these strategies do not offer a permanent solution to the problem, but rather a plan for the recovery of wild populations (Gascon et al., 2005).

These projects are a useful tool for extending the time available to mitigate wild threats and provide a viable source of animals for reintroduction into their native habitats. Many organisations contribute to this effort, primarily universities and zoos, creating a large network with a main objective: preserve species by rearing and breeding them in specialised facilities and finally reintroducing them into the wild. Eighty-four or more species of animals and plants are classified as EW by the IUCN (Dalrymple et al., 2023), suggesting that wild populations no longer exist and are represented only by captive nuclei. Furthermore, ex situ strategies sometimes have good success rates, but there are still some risks that could jeopardise the project's positive outcome.

Genetic stochasticity, particularly in amphibians with small populations, that are exposed to the risk of diffusing new pathogens in local environments where threatened species breeding centres are located, potentially represents one of the major problems of ex situ strategies. However, advances in biosecurity and safety protocols nowadays help to mitigate these risks by emphasising the maintenance of native species within dedicated facilities and, in some cases, by restricting the introduction of non-native taxa. While these measures are not directly linked to the pet trade, they reflect standard biosecurity practices aimed at preventing pathogen spillover and safeguarding local biodiversity (Zippel et al., 2011).

In terms of threatened amphibian conservation, we mention the "El Valle Amphibian Conservation Centre", located in the city of El Valle de Antón in Panama (Kolbert, 2016). This facility is dedicated to conserving several *Atelopus* species, including the Panamanian golden frog (*Atelopus zeteki*) (fig.2). The centre is part of the wider Panama Amphibian Rescue and Conservation Project. Another important centre is the "Centro Jambatu" in Ecuador, where field biologists, conservationists, educators and communicators meet to focus on the conservation of several species (http://www.anfibiosecuador.ec/). This breeding center has the world's largest and most valuable collection of *Atelopus*, with fourteen live species and twenty-eight other species of frogs, toads, and urodeles. The center is fo-

Figure 2: *Atelopus zeteki*. (© Emanuele Biggi)

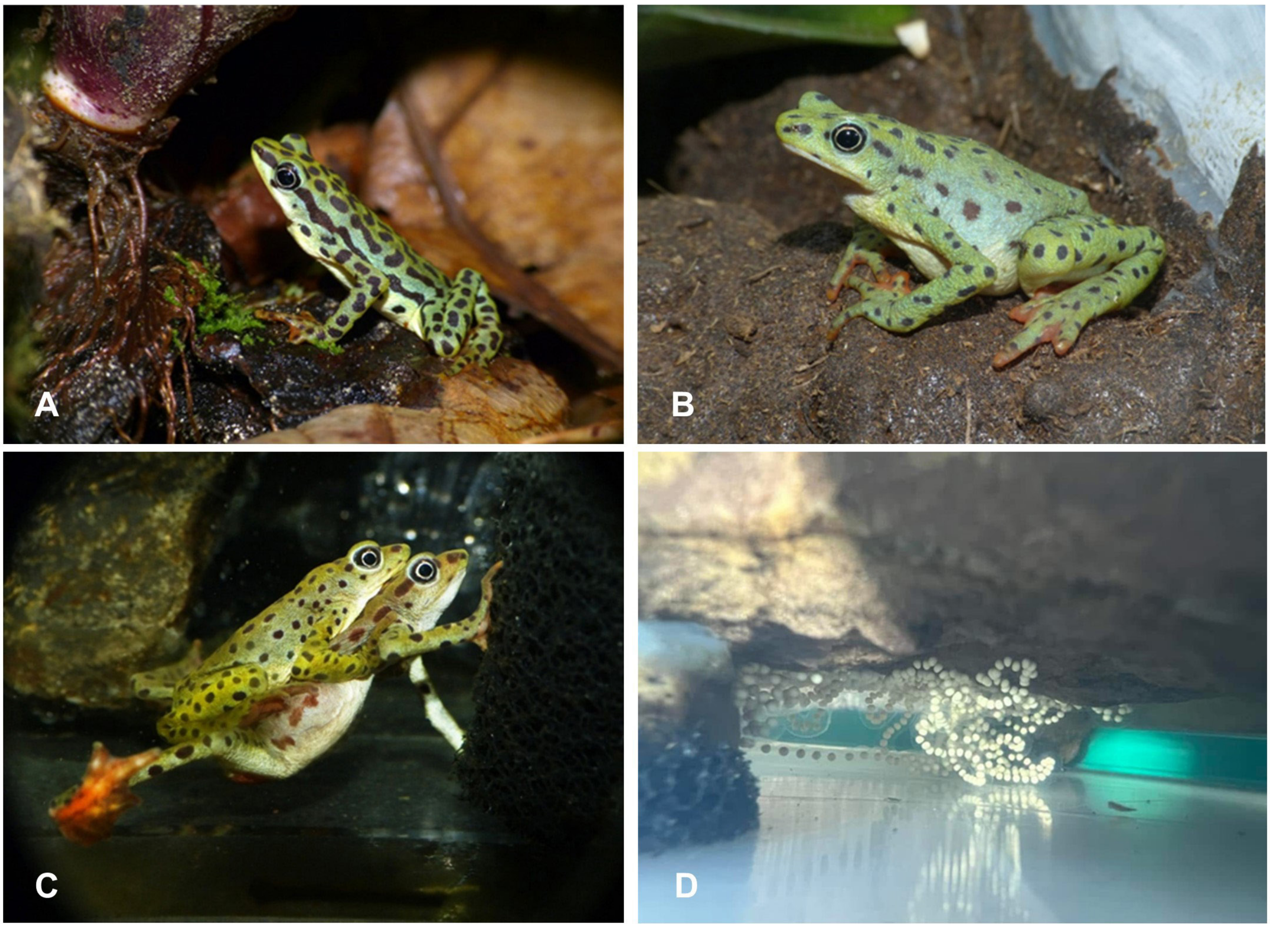

Figure 3: *Atelopus balios*. A) male; B) female. C) Amplexus D) Egg clutch. (©Thomas Ackermann)

cused not only on preserving live threatened animals, but also on preserving specimens for research and conservation purposes.

It is also crucial to specify when and how an amphibian species should be included in an ex situ conservation programme. Planning is one of the most important phases of a conservation effort, and its structure varies depending on which species deserves the attention of scientists and the available economic resources. Many amphibian taxa are featured by reproductive strategies involving many eggs and no parental care, making them suitable for short and long-term conservation activities through captivity (Griffiths & Pavajeau, 2008). However, difficulties still exist regarding the training and monitoring of reintroduced individuals (Bloxam et al., 1995).

The Citizen Conservation project for *Atelopus balios*

The Citizen Conservation (CC) is a programme developed in 2018 by the German organisation Frogs & Friends (https://citizen-conservation.org/), with the aim to include private animal breeders in ex situ conservation projects, producing a connection between institutions and hobbyists and having a positive impact on many threatened species. CC currently has an Italian chapter, which is managed by the Italian Gekko Association (Di Martino & Carsana, 2025).

CC's partners actually raise twenty species of frogs, toads and fish. Here, we provide some information on CC's initiatives concerning *Atelopus balios*, also known as the Rio Pescado stub-foot toad (Figs. 3A-B). This anuran

was once widespread on the riverbanks and in the lowland valleys of southwestern Ecuador (Peters, 1973). *Atelopus balios* is recognisable by its light green livery with black spots on the back and the characteristic orange toes found in many Anura taxa (Monnet et al., 2002; Olivera-López et al., 2021). Females are larger than males, with a snout-to-vent length (SVL) of 40–50 mm in females and 30–38 mm in males (Fig. 3A, B) (Buttermore et al., 2024).
Atelopus balios was thought to be extinct, but it was rediscovered in 2010, fifteen years after it was last seen in 1995 (Hance, 2011). Since then, it has been included in many projects aimed at saving it from extinction. CC is one of these projects, offering its support for the ex situ conservation programme, including captive husbandry, alongside other zoos and aquaria.

Breeding, rearing tadpoles and toadlets

Similarly to other harlequin toads, *Atelopus balios* has been bred in captivity by the Centro Jambatu and Amaru Bioparque in Cuenca and is currently included in the CC's conservation activities. The Rio Pescado Stubfoot Toad breeding programme involves keeping diverse individuals in a controlled environment using naturalistic-style terrariums, or keeping the animals in a simpler, more hygienic set-up . The former method is favoured by private keepers, primarily for aesthetic reasons. The overall size of the terrariums is directly proportional to the number of toads. This is due because *Atelopus* usually feeds on large quantities of small insects: providing substantial space for a small group of animals makes this behaviour quite challenging. Temperatures should be 22-25 °C during the day and 19-22 °C at night, in line with the low elevations at which these anurans live. The diet in captivity mostly consists of small hexapods such as *Drosophila melanogaster, D. hydei,* Collembola*, Thermobia domestica, Megoura viciae, Callosobruchus maculatus,*

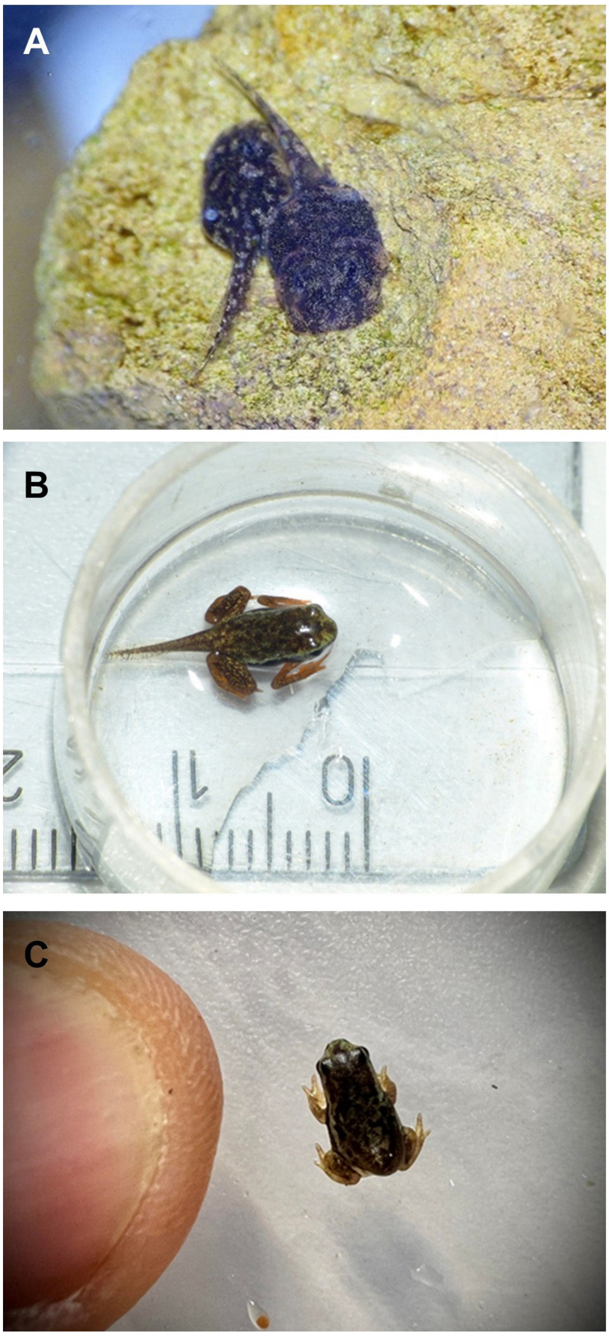

Figure 4: *Atelopus balios.* A) tadpoles; B) individual with not fully resorbed tail; C) neo-metamorphosed (© Thomas Ackermann)

and *Acheta domesticus* nymphs and a vitamin supplement to ensure complete nutrition, which is extremely important for their overall health (Buttermore et al., 2024).
When the female toads' bellies are swollen with eggs, they tolerate the males' attempt for amplexus and are put in a special aqua-terrarium simulating a gently flowing stream with oxygenated water. Spawning tanks have

Figure 5: A) Typical set-up for juveniles of *Atelopus balios;* B) Naturalistic-style terrarium for adults. (© Thomas Ackermann)

a water level of 4-15 centimetres, lots of rocks, bubbling stones and a pump with a moderate flow to ensure good aeration. The water is not heated and has a neutral pH with low water hardness. The females usually lay their eggs under rocks and other structures in the tank. Amplexus can extend for several days, with oviposition lasting up to nine hours, during which time the pair periodically emerge from the water to breathe (Fig. 3C). Each clutch consists of strings of several hundred unpigmented eggs, which hatch after around ten days (Fig. 3D) (Agustine et al., 2024). From hatching onwards, the tadpoles (Fig. 4A) attach themselves to any available structure in the aquarium, thanks to the anatomy of their buccopharyngeal area and the presence of a gastromyzophorous organ on their abdomen (Coloma & Lötters, 1996). This morphological feature is also present in the tadpoles of other *Atelopus* species. The morphology of the tadpoles is an adaptation to living in fast-flowing waters (dos Santos Dias & Anganoy-Criollo, 2024). The tadpole aquarium setup, which includes rocks, aeration stones and moving pumps, is not much different from the breeding aqua-terrarium of the adults. The tadpoles (Fig. 4A) take between 90 and 150 days (three to five months, depending on temperature and food supply) to leave the water, at which point they start feeding on springtails, mites and other tiny invertebrates once their tails have fully disapperead (Fig. 4B–C). The tiny froglets should be housed in plastic boxes containing wet clay and foliage. Artificial plants offer cover and shelter, and misting multiple times per day ensures proper hydration (Fig. 5A, B).

Other *Atelopus* species in ex situ and reintroduction programs

While *Atelopus balios* provides an excellent model for general harlequin toad husbandry and captive breeding, it is one of many species included in such ex situ conservation programs. Despite successes in captive propagation, the permanent reintroduction of captive-bred offspring into their native habitats remains a significant and complex challenge. However, preliminary soft-release trials have been conducted for a few species to study the crucial transition from captivity to the wild. For instance, a release trial of the Critically Endangered *Atelopus varius* in Panama involved 458 captive-bred individuals to assess eco-ethological aspects, including dispersal and threat exposure (Klocke et al., 2023). This trial highlighted the difficulties in post-release monitoring: the frogs dispersed rapidly and were difficult to re-encounter. Effective tracking was achieved via radio transmitters applied to a small subset of individuals; even then, only half of the 30 radio-tagged individuals were trackable after 10 days, and no frog was sighted after 36 days post-release. The low re-encounter rates thus prevented insight into the animals' long-term fate. Crucially, the captive-bred individuals did not regain detectable levels of tetrodotoxin (TTX), the species' primary skin toxin, during the observation period.

Such acclimation and soft-release efforts often utilize mesocosms, cage-like enclosures placed within the species' original distribution area. These structures are designed to mimic the natural habitat, allowing the anurans to forage on naturally occurring invertebrates without artificial feeding. This same technique was employed for *A. limosus* (Estrada et al., 2022). After 27 days in the field mesocosms, the frogs' skin bacterial communities became comparable to those of wild conspecifics, supporting the hypothesis that the natural environment helps restore the skin microbiome. In terms of body condition, the overall average weight remained stable, consistent with the minimal change observed in females (a slight, non-significant loss) and the weight gain recorded in males. However, similar to *A. varius*, the individuals placed in mesocosms did not acquire the natural toxins. These trials collectively confirm the value of mesocosms for systematic monitoring of physiological and microbial changes during the critical transition period, even though the challenge of toxicity recovery persists.

Conclusions

Ex situ conservation involves maintaining plants and animals outside their native habitat. This approach is primarily adopted when species are facing severe threats and the collection, rearing and breeding of individuals is the only means of preserving their evolutionary history. In the case of amphibians, for example, captive breeding not only safeguards many species from imminent extinction, as illustrated by the case of the *Atelopus* genus, but also complements in situ efforts. In addition to preventing population collapse, ex situ initiatives often serve as repositories of genetic diversity, ensuring that unique lineages are not lost even when wild populations decline dramatically.

Habitat restoration and the reintroduction of captive-bred offspring can significantly contribute to the stability of trophic networks, allowing species to recover ecological roles that might otherwise disappear. Programmes such as the CC, which is now active in Italy, involve experienced private breeders across Europe and demonstrate how integrating ex situ husbandry with field-based studies provides a sustainable model for long-term preservation. These collaborative frameworks also promote the exchange of knowledge between institutions, researchers and citizen scientists, fostering a broader awareness of the ecological importance of species protection.

Extending these practices to a wider range of species and advancing husbandry science will be essential to strengthening global conservation strategies, particularly for amphibians but ultimately for biodiversity as a whole (Conde et al., 2021; Bertram & Vivier, 2020). Furthermore, integrating ex situ and in situ efforts is critical in the context of climate change, where adaptive management is necessary (Byers et al., 2013). Looking ahead, the success of conservation programmes will increasingly depend on a combination of technological innovation, such as cryopreservation and genomic monitoring, and the capacity to adapt management practices to rapidly changing environmental conditions.

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