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Perspective

Art as a source of historical biodiversity data

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SUMMARY

Art has long reflected humanity's relationship with the natural world and is increasingly recognized as a valuable source of data for reconstructing past biodiversity. Here, we synthesize evidence from prehistoric cave art, historical illustrations, and literary arts to document how artworks can be used to inform our understanding of extinct species, historical population dynamics, distributional shifts, and temporal changes in species' traits. We also explore how artworks composed of biological materials such as feathers, bones, and wood can offer insights into species interactions with humans. Although artworks present unique opportunities for biodiversity research, there are limitations and challenges associated with interpreting the biodiversity data we derive from them. We advocate for interdisciplinary collaboration among art historians, archaeologists and biodiversity scientists to unlock the full potential of art in biodiversity science.

INTRODUCTION

Understanding past biodiversity is important for biodiversity conservation and ecological restoration.[1] To reconstruct past biodiversity, ecologists have traditionally relied on sources such as fossils and museum specimens to study changes in biodiversity that have occurred in the past decades, centuries, or millennia.[2–4] In recent years, additional and unexpected sources of information, including data gleaned from historical paintings[5,6] and photographs,[7] have been shown to faithfully reflect past biodiversity. These sources, and others like them, are intimately connected to human memory and may contribute to increasing the public pressure for biodiversity conservation.[8]

Art is an expression of human creative skills and imagination, and some artworks illustrate remarkably realistic depictions of fauna and flora. For example, genotypes of predomesticated horses correspond to coat-color patterns found in ∼25-ka cave paintings at Pech-Merle, France.[9] Moreover, Upper Paleolithic artists (*Homo sapiens*) were more accurate than modern illustrators in portraying how quadrupeds walked.[10] As biodiversity scientists, we assert that artworks offer a valuable data archive that could complement traditional ecological data in reconstructing (pre)historical biodiversity baselines and temporal changes in species distributions, abundances, and morphology.[6,11] In this review, we summarize the types of artistic forms that document past biodiversity, outline key research topics that can be addressed using biodiversity in art, and discuss the limitations and future directions of this approach.

FORMS OF BIODIVERSITY IN ART

Prehistoric cave paintings and rock art

Humans began recording biodiversity in prehistoric cave art and rock paintings depicting animal species are common (Figure 1). For example, 51.2 ka engravings, paintings, and petroglyphs from Leang Karampuang island of Indonesia represent the oldest known figurative art and depict local wildlife, including wild pigs and bovids.[12] In Australia, the oldest *in situ* rock painting, dated to 17.5 ka, portrays a kangaroo.[13] Among 5,786 depictions from 113 European Paleolithic caves, 54% depict animal species,[14] mostly large-bodied mammal species such as horses (*Equus ferus*) and lions (*Panthera leo*) in France,[15] giant sloths (*Glossotherium lettsomi*) in Colombia,[16] woolly mammoths (*Mammuthus primigenius*), and woolly rhinoceroses (*Coelodonta antiquitatis*) in Russia.[17] In North America, the oldest known rock art (*ca.* 14 ka) includes depictions of bighorn sheep (*Ovis canadensis*),[18] and this species accounts for >90% of all the animals depicted in the rock art of California's Coso Range (dating to 10 ka).[11]

Although depictions of mammals are nearly global and dominate prehistoric cave paintings and rock art, plants and insects also are depicted.[14,19] Bees are represented frequently in cave art because of the importance of honey and wax; the oldest examples of depicted bees are found in Egyptian carvings (*ca.* 8 ka).[19]

Historical paintings

Historical painters have vividly depicted organisms identifiable to particular species (Figure 2). In China, for example, at least 67 bird species have been identified from 158 bird-flower paintings from the Song dynasty (960–1279 C.E.), including the

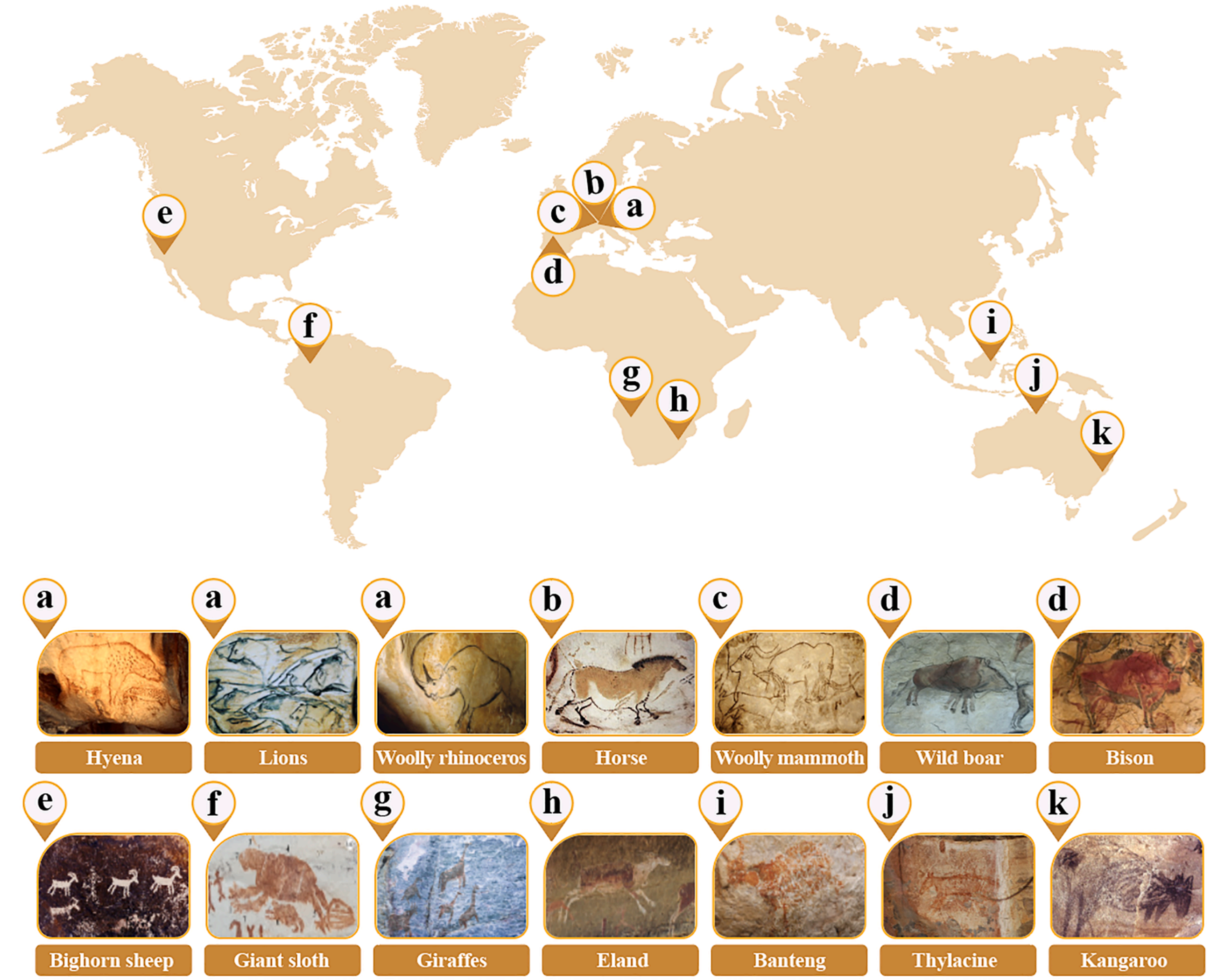

Figure 1. Map of rock art with animal depictions

(A) The Chauvet Cave, France (credit: Inocybe at French Wikipedia and HTO; public domain); (B) the Lascaux Cave, France (credit: public domain); (C) the Rouffignac Cave, France (credit: public domain); (D) the cave of Altamira, Spain (credit: HTO and Museo de Altamira y D. Rodríguez; public domain and CC BY-SA 3.0); (E) Grapevine Canyon of Nevada, USA (credit: Calsidyrose; CC BY 2.0); (F) the Serranía de la Lindosa, Colombia (credit: Iriarte et al.; CC BY 4.0); (G) the Tsodilo Hills, Botswana (credit: Oliver Vass; CC BY-SA 3.0); (H) San/Bushman rock art, South Africa (credit: Lukas Kaffer; CC BY-SA 3.0); (I) the Lubang Jeriji Saléh cave, Indonesia (credit: Luc-Henri Fage, www.fage.fr; public domain); (J) Ubirr, Australia (credit: nettispaghetti; CC BY-SA 2.0); and (K) Myuna Creek, Australia (credit: Clytemnestra; CC BY-SA 3.0). All photos were obtained from Wikimedia Commons.

common Eurasian tree sparrow (*Passer montanus*) and Eurasian magpie (*Pica pica*).[5] The Song Emperor Huizong (1082–1135), also a famous artist, documented the earliest known natural hybrid between the Golden Pheasant (*Chrysolophus pictus*) and the Lady Amherst's Pheasant (*Chrysolophus amherstiae*) (Figure 2A).[20] In Egypt, artistic representations of 38 large mammal species, including giraffes, lions, and hippopotamuses depicted on tombs, knife blades, and funerary palettes have been used to infer local extinctions over a 6,000-year period.[21] Dutch artist Rachel Ruysch (1664–1750) created detailed floral paintings of many native and exotic species (mostly plants; Figure 2B). In a recent collaboration, art historians and botanists jointly analyzed 16 of Ruysch's still-lifes spanning her early, middle, and late career, producing species inventories for each work and determining the native ranges of the plants she depicted.[6,22] These inventories revealed a hump-shaped pattern in species richness across her career, with particularly diverse bouquets in the early 1,700s and in a c. 1,735 painting that includes 36 species, 19 of which are non-European.[6,22] By mapping these taxa using modern floristic databases, the team showed that Ruysch combined familiar Dutch market flowers with rare "botanical Easter eggs" from Asia, Africa, and the Americas, thereby documenting the expansion of Dutch colonial trading and the horticultural networks that granted her access to these plants.[6,22] Throughout Europe, paintings from the 16th through 19th centuries have recorded numerous types of large trees

Figure 2. Examples of historical paintings from which biodiversity data can be inferred

(A) An avian hybrid between the Golden Pheasant and the Lady Amherst's Pheasant, depicted by Emperor Huizong of Song dynasty (credit: public domain); (B) a rose by Rachel Ruysch (credit: Sailko; CC BY 3.0); (C) large plane trees (*Platanus* sp) depicted by Vincent Van Gogh (credit: Howard Agriesti; public domain); (D) fish market by Frans Snyders (credit: Kunsthistorisches Museum; public domain); (E) watermelons in the 17th century painted by Giovanni Stanchi (credit: Christie's; public domain). All photos were obtained from Wikimedia Commons.

(Figure 2C), fishes, and other aquatic species (Figure 2D), as well as vegetables and fruits,[23] and these paintings have provided insight into the evolution of plant-based food (Figure 2E), and their changes in shape, size, and color during domestication.[24] In addition, 19th-century landscape paintings have provided key details about forest community structure, species composition, microhabitat features, and past environmental conditions of that period.[25] Since the mid-19th century, photographs, films, and wildlife documentaries increasingly have replaced paintings as visual documentation of species occurrences and ecological changes, and these also can help identify and establish biodiversity baselines.[26–28]

Apart from historical paintings depicting terrestrial species, aquatic species are also a constant motif in art,[29–32] especially fishes.[31] These paintings accurately capture species morphology, biogeography, seasonality, and fishing practices, making them a valuable source documenting ecological shifts, including changes in population size, species distribution range, and species dominance over several centuries.[29–31]

Literary arts

Literary works, including poetry,[33] fiction,[34] and song lyrics[35] also offer valuable information on past biodiversity. For example, in a classic Chinese essay, Yu Han (768–824) describes frequent human-crocodilian conflicts in Guangdong (southern China), where no wild crocodilian species now occur today. That essay, together with fossil and archaeological evidence, led to the discovery of a previously unknown, now-extinct crocodilian species, *Hanyusuchus sinensis*, named in honor of the poet. This species is thought to have gone extinct around the 15th century.[33] In addition, the now critically-endangered Yangtze finless porpoise (*Neophocaena asiaeorientalis*) is mentioned in at least 724 ancient Chinese poems, which have helped to document its history of change by the hands of humans.[36] In Greece, epic poems that reference 71 animal taxa have been used to reconstruct the extant fauna during Homer's time (*ca.* 800 B.C.E.).[37] In Japan, monographs dating to the 18th century written by early naturalists contain detailed observations of whales and their epizoic barnacles[38] that provide the first recorded evidence of the trans-Pacific migration of the black turtle (*Chelonia mydas agassizii*) between 1600 and 1868.[39]

BIOLOGICAL MATERIALS IN ART

Bird feathers, animal bones, and teeth long have been used by humans as artistic materials and as symbols of status and cultural identity. As early as 44 ka, Neanderthals used bird feathers of the Eurasian black vulture (*Aegypius monachus*) and golden eagle (*Aquila chrysaetos*) for ornamental purposes.[40] In Hawai'i, traditional featherwork reached an extraordinarily extractive level. A single ‘ahu‘ula (feather cape) crafted by ancient Hawaiians may have consisted of millions of feathers collected from thousands of birds (Figure 3). For instance, the "ahu"ula of Kamehameha, the first king of the Hawai'ian islands, used feathers from over 60,000 individuals of the Hawaii Mamo (*Drepanis pacifica*). Such overharvesting likely exacerbated the extinction of this species by the early 20th century.[41] In New Zealand, Māori feather cloaks incorporated feathers from more than 30 bird species, although most came from a single species, the North Island brown kiwi (*Apteryx australis mantelli*).[42] In Mexico, the Aztec empire annually harvested 6,200–31,000 resplendent quetzals (*Pharomachrus mocinno*), whose feathers were used for ceremonial headdresses and artwork.[43] In China, feathers from the Reeves's pheasant (*Syrmaticus reevesii*) were commonly used

Figure 3. Artwork made of bird feathers and animal mummies
(A) An ʻahu'ula (Hawaiian feather cloak) housed at Bishop Museum (credit: Hiart; CC0 1.0); (B) an Aztec feather headdress from National Museum of Anthropology, Mexico City (credit: Gary Todd; CC0 1.0); (C) 19th-century kingfisher feather hairpins (credit: Nalin Singapuri; CC By-SA 4.0); (D) monkey and dog mummies from Cairo Egyptian Museum (credit: Namiac; CC By-SA 4.0); (E) detail of the bottom border of a Māori Kiwi feather cloak (credit: Stuartyeates; CC BY-SA 3.0). All photos were obtained from Wikimedia Commons.

to make elaborate headgear for traditional Chinese operas,[44] and the iridescent blue feathers of kingfisher (Aves: Alcedinidae) were prized as luxury decorative art materials.[45]

Some of the earliest known symbolic artifacts date to >130 ka, when Neanderthals crafted jewelry using modified claws of the white-tailed eagle (*Haliaeetus albicilla*).[46] In the Gilbert Islands (Kiribati), Indigenous communities historically used shark teeth to construct tools and weapons, thus documenting the presence there of spot-tail (*Carcharhinus sorrah*) and dusky (*Carcharhinus obscurus*) sharks during the late 19th century.[47] Bone carvings in the Americas from at least 13 ka include examples of engraved animal bones (possibly that of a mammoth or mastodon).[48] In ancient Egypt, scarab beetles (Scarabaeidae) were fashioned into amulets and jewelry, symbolizing rebirth and protection,[49] and they were also commonly used as materials for other art.[50]

Ancient buildings and related structures can also provide valuable insights into past biodiversity. For example, in the Forbidden City of China, numerous large, old nanmu trees (mostly *Phoebe zhennan* and *Phoebe hui*) were sourced from remote southern regions of China and used in 17th-century construction.[51] However, as these large old-growth trees were harvested, fast-growing pines and other tropical trees were substituted for nanmu.[51] Similarly, some of the oldest preserved roof structures in Europe have been identified in Norwegian churches built from identifiable local oak (*Quercus* sp.) and pine species (*Pinus* sp.).[52]

Beyond the use of feathers, bones, and wood in artistic and functional objects, human and animal mummies (e.g., cats, ibises, and crocodiles in Egypt) offer unique archives of physical specimens of extant and now-extinct taxa (Figure 3). These remains have enabled reconstructions of past population health, genetic diversity, body size, and even diet and parasite communities.[53,54] Moreover, the carved coffins, painted wrappings, and funerary amulets associated with mummies frequently depict a wide array of flora and fauna, shedding light on the historical distributions and cultural significance of many different species.[19,21,55]

USING BIODIVERSITY PORTRAYED IN ART FOR ECOLOGICAL RESEARCH

The species represented in art can provide valuable information on spatial and temporal changes in biodiversity. Artwork can be dated, locations can be inferred, and morphological traits of depicted species can be measured and cross-referenced. With current technologies, animal and plant materials used in artwork can be assessed using a variety of multi-omics (e.g., genomic and metabolomic) investigations, yielding additional comparative ecological and evolutionary data.

Recording extinct species

Cave art across the world preserves images of numerous extinct megafauna species, including the woolly mammoth, woolly rhinoceros, giant sloth, auroch (*Bos primigenius*), and cave lion (*Panthera spelaea*)[16,17,56,57] (Figure 1). In northern Australia, prehistoric rock art depicts the extinct Tasmanian tiger (*Thylacinus cynocephalus*) and marsupial lion (*Thylacoleo carnifex*).[58] Similarly, rock engravings in the Asphendou Cave of Greece document an extinct endemic deer species, providing clues to the island's prehistoric biodiversity.[59] Natural-history illustrations document extinct species such as the dodo (*Raphus cucullatus*)[60] and the passenger pigeon (*Ectopistes migratorius*).[61] Feathered capes and cloaks often incorporate materials from now-extinct bird species, serving as key physical records of lost biodiversity.[41]

Assessing population dynamics

In addition to extinction, art can also serve as a valuable source to assess population dynamics, as artwork often features common species that were prevalent at the time of their creation. Bird and flower paintings of the Song dynasty in China depicted at least 67 species, the majority of which are common species.[5] However, species such as the Yellow-breasted Bunting (*Emberiza aureola*) and the Blue-crowned Laughingthrush (*Pterorhinus courtoisi*), now critically endangered, also appear in these paintings, implying that they may have been once more widespread and abundant. This finding aligns with observations demonstrating that these species may be suffering dramatic population declines in recent decades.[62,63] Beyond paintings, historical photographs have proven useful for documenting long-term population changes and shifting baseline syndromes.[7] On the island of Gran Canaria, historical photographs taken by recreational fishers revealed a dramatic reduction in the abundance of top predators, a trend consistent with results from field surveys.[28] In Japan, *Gyotaku* (fish rubbings) has been used as a source of historical biodiversity data to capture how fish species in various parts of the oceans have changed due to overfishing.[64,65]

Mapping historical species distributions

Art is a largely ignored source for studying species' past distributions. *Zaglossus*, the largest egg-laying mammal now endemic only to New Guinea, has been extirpated from Australia. Its historical presence in northern Australia is supported by Aboriginal rock art from Arnhem Land and corroborated by Pleistocene fossil remains.[66] Additionally, rock-art depictions of the lesser kudu (*Tragelaphus imberbis*), aurochs, and African wild ass (*Equus africanus*) in north-western Arabia challenge previous assumptions that they were absent from the Arabian Peninsula.[67] Analysis of 366 Chinese poems containing specific occurrence records of the Yangtze finless porpoise led to the inference that its range has contracted by at least 65% over the past 1,400 years; 91% of the inferred reduction in its distribution within tributaries and lakes has resulted from dam construction and other human activities.[36] Other historical documents, including structured written records and gazetteers, can be used to study changes in geographic ranges,[68–70] especially for well-represented large mammal species such as tigers (*Panthera tigris*)[68] and gibbons.[71]

Tracking trait change

Artwork that realistically portrays species distinctive features such as body size, shape, and color can serve as valuable materials for studying trait changes over time.[9] By combining analyses of ancient DNA and cave-art depictions, researchers confirmed that prehistoric artists accurately illustrated distinct morphological forms, such as the replacement of the steppe bison by a hybrid form in Western Europe during the Last Glacial Maximum (20–26 ka).[57] In the Mediterranean region, ancient artworks revealed that body size of the dusky grouper was significantly larger in the past, consistent with evidence from bone remains in human settlements.[72]

Reductions in body size have also been observed through analyses of historical photographs. Photographs taken on the island of Gran Canaria demonstrate that the mean total length of the dusky grouper declined significantly, from 100 cm before 1980 to <40 cm after 2009.[28] Similarly, McClenachan measured and analyzed 1,275 fishes from photographs taken in Key West, Florida, and found the mean fish size declined from ∼20 kg in 1956 to 2.3 kg in 2007, and the average length of sharks declined by >50%.[73] Similar findings were reported for the small-tooth sawfish (*Pristis pectinata*), whose historical images show substantial size reductions over time.[74]

Exploring species interactions with humans

Art can convey important messages about the early domestication of plant and animal species and the evolving relationships between humans and biodiversity. Historical paintings have documented the earliest known avian hybrid between pheasant species,[20] the domestication of the brown rat (*Rattus norvegicus*),[75] the development of modern fruits through selective breeding,[24] and the history of domesticating birds as pets.[5] For example, the 17th-century Italian still-life painter, Giovanni Stanchi depicted watermelons with a swirled, pale interior, illustrating their morphology before it was selectively bred for heartier red flesh.[24] Eight-thousand-year-old engravings from northwestern Saudi Arabia provide the earliest evidence of dogs used for hunting.[76] Artwork from an Egyptian tomb depicting a cat eating fish under a dining room table offers an early representation of cat domestication.[55]

BIODIVERSITY IN ART SHOULD BE INTERPRETED WITH CAUTION

Although artworks can be a complementary source of data about past biodiversity, art is also a product of artists' creative imagination, stylistic choices, and preferences. In addition, artworks are influenced by the complex relationship between art practice and the living world, often reflecting cultural, historical, and scientific dynamics.[34,60,77,78] Therefore, inferences about biodiversity drawn from art should integrate art-historical expertise. A recent analysis of prevailing environmental conditions inferred from the paintings of Turner and Monet provides an illustrative example. The artists' later works became increasingly hazy and diffuse, and this apparent stylistic shift could have reflected increasing air pollution in 19th-century London.[79] However, the changes could also be explained by evolving artistic styles and techniques.[80]

Identifying species depicted in art is also challenging, particularly because the artists may not have been educated naturalists and their depictions were stylized.[5] Consequently, claims regarding the presence of extinct species based solely on art have been controversial and subject to debate.[16,81] Moreover, the appearance of a species in art does not necessarily imply its contemporaneous occurrence at a particular locality and time. For example, many of the bird feathers used in Māori feather cloaks originated through inter-island feather trade, complicating interpretations of the geographic origin and historical abundance of the birds.[42] These challenges underscore the importance of integrating multiple lines of evidence, including archaeological, molecular, and historical records, involving and engaging art historians, when interpreting biodiversity data from artworks. This is likely to produce fruitful scholarship as exhibited in recent Art × Science collaborations.[6,22]

Finally, the artistic representation of biodiversity in art is taxonomically biased and thus data must be critically and cautiously evaluated. For example, a comprehensive study examining 5,786 depictions in 113 European paleolithic caves identified only four (0.07%) featured plants, substantially less than featured animals (53.7%).[14] Representations of insects, reptiles, and amphibians also are notably underrepresented in historical and prehistorical art.[82,83] Depicted species may also originate predominantly from specific regions, exhibit particular sizes, or reflect culturally significant traits, thus resulting in a non-representative record of past biodiversity. For example, a study using 3,158 images of artistic portrayals and photographs found a decline in rhinoceros-horn length across species over time,[84] but captive (zoo) individuals were overrepresented in the dataset.[85] As shown for Early Modern aquatic paintings,[29] artworks can be understood as passing through successive "sieves"—such as aesthetic conventions, patronage, and market demand—that filter which organisms are represented and how, reinforcing these non-random biases.

BUILDING A METHODOLOGICAL FRAMEWORK AND INFRASTRUCTURE FOR REALIZING BIODIVERSITY SCIENCE × ART

This review has synthesized the diverse ways in which art, both representational (e.g., cave art, historical paintings, and literature) and material (e.g., feathers, bones, and wood used in artifacts and architecture), encodes valuable information on past biodiversity. To move from review and recognition to actionable science, we recommend a methodological framework for harnessing art-based biodiversity data.

First, progress will depend on tightly scoped pilot case studies in which art historians, curators, and biodiversity scientists co-analyze well-defined bodies of artworks. The collaboration on Rachel Ruysch's floral still-lifes, outlined earlier, provides one such template: art historians first delimit a coherent set of works with secure dating and provenance and clarify workshop practices and compositional conventions, while biodiversity scientists derive species inventories, geographic origins, and relevant traits from high-resolution images.[6,22] From pilots of this kind, teams can co-develop protocols for annotation, document sources of uncertainty, and decide which types of artworks are suitable for quantitative ecological analyses.

Building on these pilots, artworks representing biodiversity can then be more systematically digitized and annotated following standardized protocols, with metadata on provenance (e.g., time and place of origin), cultural context, and depicted taxa.[5,11,14,58,67] Collaboration with museums, archives, and crowdsourcing platforms can facilitate large-scale image annotation and species identification. Advanced tools, such as AI-driven image analysis, hold promise for rapidly extracting taxon and trait information from artwork and should be piloted with these curated datasets.[86] Second, a central open-access database should be established to aggregate and curate these records, ideally linked with established biodiversity and museum collections. To establish such a repository, we can also compile information from currently available databases on art, such as the Biodiversity Heritage Library (https://www.biodiversitylibrary.org/), the European Prehistoric Art (http://www.europreart.net/index.htm), Cave Art (https://www.creap.fr/Database.htm), and Chinese Classics (https://ancientbooks.cn/) databases. Third, to ensure scientific reliability, all compiled data should undergo multi-layer quality control and cross-validation using independent sources such as fossils, archaeological finds, or genetic evidence when available.[33,57] Crucially, such quality controls should be interdisciplinary: art-historical peer review of dating, attribution, and stylistic interpretation is as important as biological validation, and many decisions about which images can be treated as ecological evidence often cannot be automated. Community-building, through targeted workshops, interdisciplinary training, and collaborative research networks, will be essential to build capacity and foster sustained partnerships. Importantly, artworks do not passively document biodiversity but are shaped by cultural practices and scientific debates.[29,79,80] Art historians who are familiar with an artist's style, workshop practices, and patronage networks are therefore indispensable partners for determining which works can support ecological inference, as exemplified by the Ruysch case described earlier.[6,22] Finally, these efforts must respect legal, ethical, and cultural sensitivities, ensuring proper sharing and attribution of digitized artworks, especially those of indigenous or protected heritage.

By proposing these tangible pathways, we aim to not only highlight the promise of art as a biodiversity data source but also provide a roadmap for turning this unconventional archive into a robust complement to established ecological and historical research.

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AUTHOR CONTRIBUTIONS

J.L. conceptualized the initial idea and wrote the first draft of the paper; C.D. provided feedback and helped to substantially revise the manuscript draft and support figure development.

DECLARATION OF INTERESTS

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