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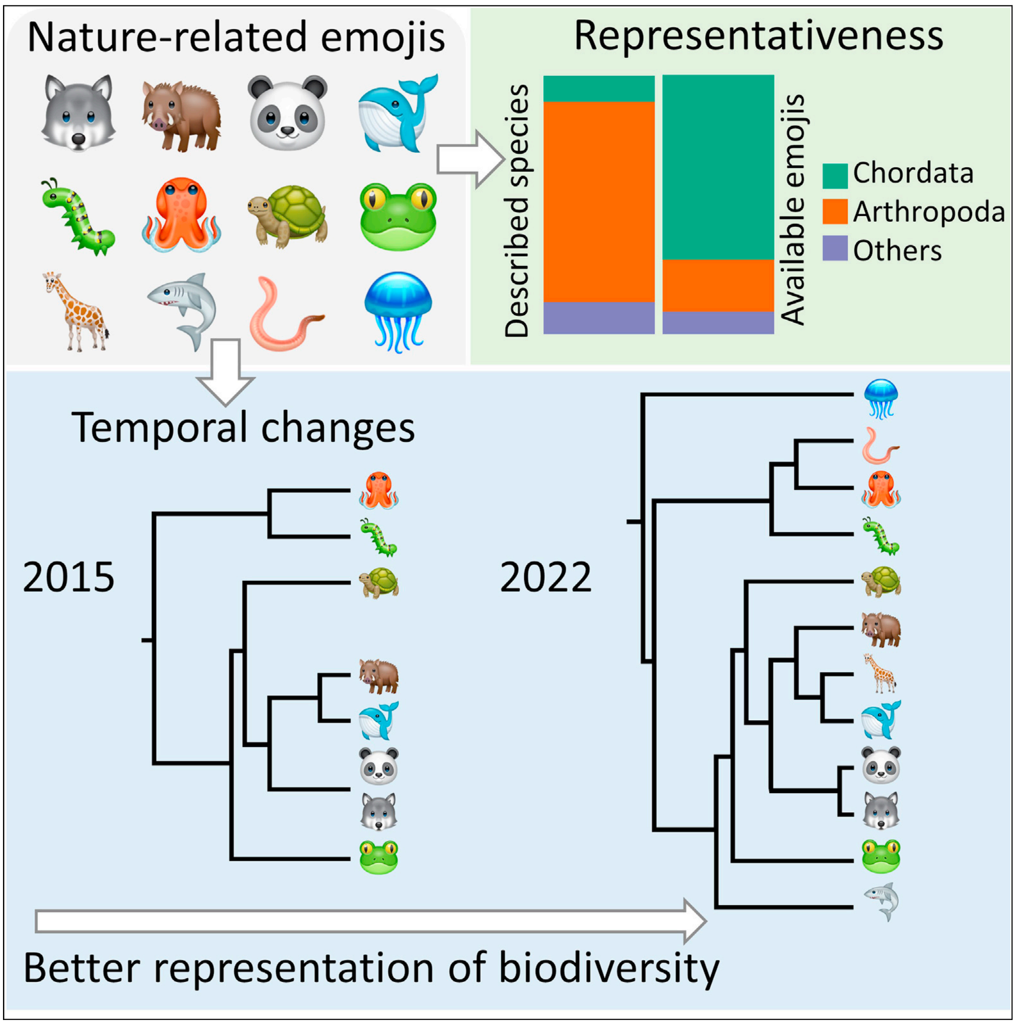


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## Highlights

Currently available emojis encompass a broad range of animal species

Plants, fungi, and microorganisms are underrepresented in the current emoji set

Within animals, vertebrates are overrepresented and arthropods are underrepresented

Recent additions allow a better representation of animal phylogenetic diversity

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# Biodiversity communication in the digital era through the Emoji tree of life

Stefano Mammola,[1,2,3,6] Mattia Falaschi,[4,6,7,*] and Gentile Francesco Ficetola[4,5,6]


## SUMMARY

**Emojis enable direct expressions of ideas and emotions in digital communication, also contributing to discussions on biodiversity conservation. Nevertheless, the ability of emojis to represent the Earth's tree of life remains unexplored. Here, we quantified the taxonomic comprehensiveness of currently available nature-related emojis and tested whether the expanding availability of emojis enables a better coverage of extant biodiversity. Currently available emojis encompass a broad range of animal species, while plants, fungi, and microorganisms are underrepresented. Within animals, vertebrates are significantly overrepresented compared to their actual richness, while arthropods are underrepresented. Notwithstanding these taxonomic disparities, animal taxa represented by emojis more than doubled from 2015 to 2022, allowing an improved representation of both taxonomic and phylogenetic diversity, driven by the recent addition of cnidarians and annelids. Creating an inclusive emoji set is essential to ensure a fair representation of biodiversity in digital communication and showcase its importance for biosphere functioning.**


## INTRODUCTION

Emojis permeate modern communication.[1] Many people routinely use thumbs-up icons to express agreement, touch a sad-smile face to lament an unclean public toilet, and incorporate multiple rows of fire emoji in text messages to convey excitement for an upcoming event. What makes emojis so successful is their unique semantic and emotional connotation, which allows for direct, simple, and ultimately powerful communication.[2] Indeed, as our world becomes increasingly digitized and interconnected, the significance of emojis is becoming universally appreciated, extending to domains as diverse as marketing, forensics, education, and health care.[3–7]

Parallel to this communication revolution, humanity is facing an unprecedented biodiversity crisis.[8] Recent estimations suggest at least one million species risk extinction[9] and hint at alarming numbers of decreasing populations.[10] As human activities erode organismal biomass,[11] phylogenetic diversity,[12] and ecosystem functionality,[13] preserving biodiversity in all its forms and facets is emerging as a central imperative of our times.[14]

Effective communication is crucial for improving awareness about biodiversity in the broader society.[15,16] With the widespread use of social media and digital platforms, nature-related content is constantly being created and shared online.[17] Organism-related emojis are used increasingly within these contents, as they provide an engaging means of conveying biodiversity-related messages to diverse audiences (Figure 1). Emojis can be deployed to encourage public support for conservation efforts, to highlight the urgency of protecting endangered species, and to captivate people to participate in biodiversity-related events. For instance, through the 2021 Clio Health Silver winning entry "Extinct Emojis" (https://amansoin.com/extinct-emojis), on the World Wildlife Day, the WWF partnered with social media companies to make emojis depicting endangered animals "extinct" (that is, unavailable to users) on social media platforms. When a user tried to use an emoji of an endangered animal, they instead received an informative post about the dwindling population of the real animal and were asked to share this post on social media to unlock the emoji and trigger donations for its conservation. In this way, emojis can serve as a powerful tool for raising awareness and promoting actions to preserve our planet's biodiversity — although the effectiveness of emoji-based communication to improve species-level conservation has never been tested explicitly.

To effectively communicate about biodiversity and its conservation using emojis, it is important to have a wide range of icons that capture the staggering diversity of life on Earth. This would enhance discussions on less popular organisms that tend not to be on our cultural radar.[18] Still, the ability of emojis to cover the actual biodiversity of our planet is unexplored, preventing us from fully assessing the extent to which online biodiversity communication benefits from the availability of a more or less diverse set of emojis. Here, we aimed to assess the diversity of organism-related emojis and their potential for communicating about biodiversity. We used Emojipedia (https://emojipedia.org), the most

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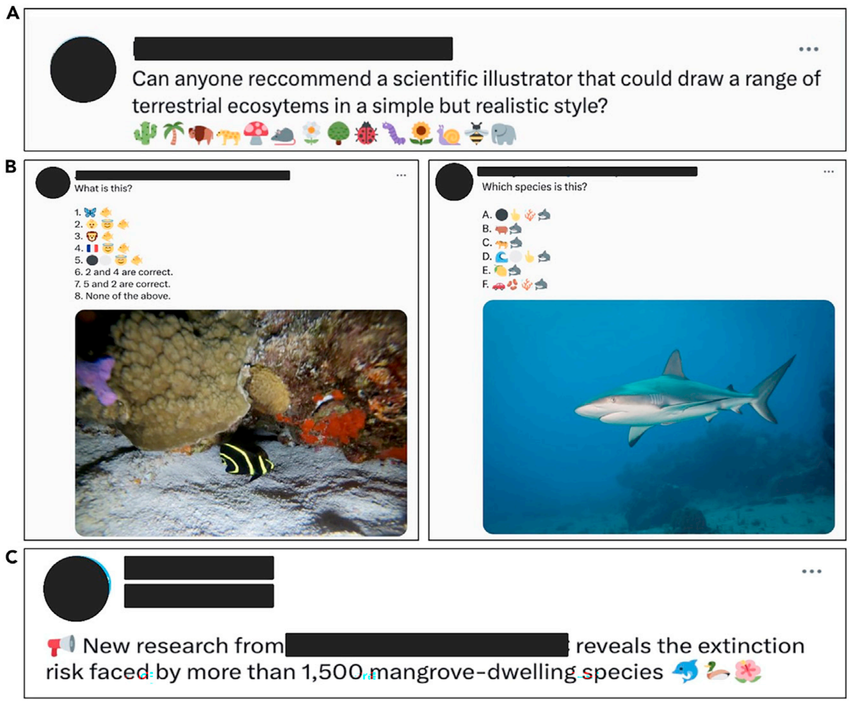


**Figure 1. Example use of nature-related emojis in communication about biodiversity and its conservation**
(A) Use of an array of emojis to convey the idea of "terrestrial ecosystems".
(B) Examples of nature-related quizzes based on emojis. Note how the lack of suitable emojis was overcome skillfully by combining multiple icons.
(C) Use of emojis for communicating about biodiversity conservation. All examples were drawn from X (formerly Twitter).

comprehensive global repository of emojis, to explore the extent to which the diversity of emojis maps onto the Earth's tree of life. First, we assessed how well emojis cover the Earth's biodiversity, and identified taxonomic biases. Next, we evaluated if the potential of emoji to convey biodiversity messages changes through time by providing a better representation of the evolutionary history of the tree of life (i.e., turnover in phylogenetic diversity). We hypothesize that emojis initially covered a limited portion of phylogenetic diversity, due to a focus on the most iconic taxa (e.g., common or charismatic mammals and birds), but that the amount of covered phylogenetic diversity increased in the last years, as neglected, poorly known taxa are added to the library of emojis. Through this exercise, we identified gaps in emoji representation and highlighted opportunities for expanding the diversity of organism-related emojis to better communicate about biodiversity and its conservation.

## RESULTS

### Emoji representativeness of the Earth's tree of life

The "Animals & Nature" section of Emojipedia includes 214 icons, 150 of which represent identifiable extant organisms (animals, plants, fungi, or microorganisms [*sensu lato*]). Some organisms were represented by more than one emoji; overall, we classified 112 distinct organisms, 92 of which were animals (Figure 2A). Only 16 plant taxa were present, whereas fungi and unicellular lifeforms each consisted of a single emoji (likely *Amanita muscaria* and *Escherichia coli*, respectively). Given this sizable numerical disparity, we focused in-depth analyses on animals. The identifiability of organisms is highly variable, with several emojis clearly representing a given species (e.g., the giant panda, the bald eagle, the monarch butterfly), many emojis representing a clearly recognizable order, family or genus (e.g., the gorilla, genus *Gorilla*; the ant, family Formicidae; or the crocodile, order *Crocodilia*), and a few emojis that only provide a vague representation of a class (e.g., the "fish" and "bird" emojis).

### Emoji representativeness of the animal kingdom

Animal emojis were dominated by vertebrates (phylum Chordata, comprising mammals, birds, reptiles, amphibians, bony fishes and cartilaginous fishes), which represented 76% of available animal emoji taxa. Arthropods (phylum Arthropoda, comprising insects, arachnids, crustaceans), the most biodiverse group of the tree of life, was the second-most represented group (16% of animal emojis), followed by molluscs, cnidarians, and annelids, which represented 4%, 2%, and 1% of animal emojis, respectively (Figure 2B). Among the species-richest animal phyla (>10,000 species), only platyhelminthes and nematodes had no emoji. Overall, there was strong taxonomic bias across animal phyla ($X^2_6$ = 890.78, $p < 0.0001$; Table S1). Vertebrates were heavily overrepresented compared to their actual richness, while arthropods were

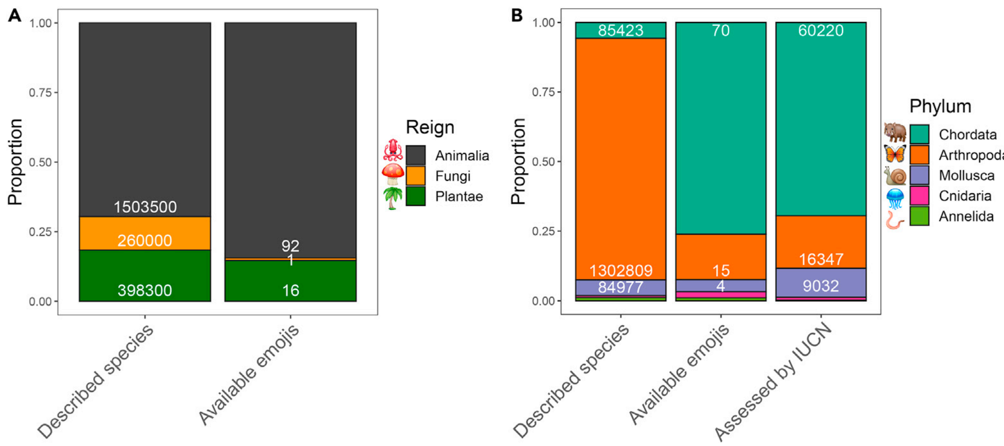


**Figure 2. Frequency of available emojis, compared to the actual number of described species**

In (A) we show the relative number of species *per* reign (Animalia, Plantae, Fungi). Note the bacteria and other unicellular organisms (represented by one emoji) are not shown in the bar chart, given the lack of reliable estimates for the number of described species. In (B) we compare the number of described species of animal *per* phylum to the number of species with emojis, and the number of species assessed by the IUCN redlist of threatened species. Only animal phyla with >10,000 described species are shown. Numbers are the actual number of described species, of emojis, and of assessed species (Table S1).

significantly underrepresented. The frequency of the other phyla was not significantly different from what was expected based on their taxonomic richness (Figure 2B; Table S1). This bias in the representation of animal biodiversity is similar to what we observe in other assessments and analyses of biodiversity, such as the International Union for Conservation of Nature (IUCN) redlist ($\chi^2_6$ = 0.82, p = 0.99; Figure 2B).

## Developments in the emoji tree of life

The number of identifiable animal taxa represented by emojis increased from 45 in 2015 to 78 in 2019, to 92 in 2022 (Figures 3 and 4). By applying a null modeling approach, we showed that from 2015 to 2019 phylogenetic diversity of animal emojis increased at a rate lower than expected based on their species richness (standardized effect size (SES) = 1.85; permutation-based p value = 0.026), suggesting that additions mostly belonged to taxa closely related to taxa already represented by emojis. However, more recent additions to animal emojis increased phylogenetic diversity significantly more than expected by chance (SES = −2.16, permutation-based p value = 0.024), due to the inclusion of several previously absent phyla that are evolutionarily very distant from formerly present taxa (Figure 3).

# DISCUSSION

Simplicity, convenience, and emotional expression are the main motivations behind users' adoption of emojis.[1] This simplicity and immediacy can serve as a valuable tool for documenting the ongoing sixth mass extinction of biodiversity, where species are disappearing not only from the physical world but also from our cultures and collective memory.[19] However, the lack of available emojis can limit communication of environmental issues. The development and maintenance of diverse and inclusive emoji sets are crucial to ensure the equitable representation of the tree of life in digital communication tools, and to effectively convey messages on the importance of all the organisms for the functioning of the biosphere. Against this backdrop, our study represents a first quantitative analysis of the taxonomic comprehensiveness of the available set of nature-related emojis, showing that while the availability of different groups has considerably expanded in recent years, taxonomic bias is still present and strong.

Such strong taxonomic bias is in line with current societal awareness of biodiversity, which tends to prioritize animals over other taxa,[20,21] a fact reflected in the abundance of animal emojis versus the scarcity of plant, fungi, and microorganism emojis. Such zoocentrism in biodiversity conservation[22] is leading to unequal attention and funding for plants and fungi compared to animals, despite the fundamental ecosystem services afforded by these organisms.[23–26] Indeed, there is a human tendency to be more empathetic and aware of organisms close to us (e.g., vertebrates), with awareness decreasing in inverse proportion to a group's evolutionary distance from *Homo sapiens*.[27] In fact, the top-20 most popular species on Earth[28] are all mammals, with bonobo and chimpanzee (the two living species most closely related to humans) being in third and fourth place, just after wolf/dog (2$^{nd}$) and humans themselves (standing in 1$^{st}$ place according to a recently proposed "popularity index": http://www.onezoom.org/popularity/index.html). This is reflected by the abundance of vertebrate emojis, particularly mammals.

An uneven availability of emojis across reigns and phyla/divisions may reinforce biases by impeding communication for underrepresented taxa. For instance, a colleague at a recent biodiversity conservation meeting shared her struggle to communicate online about her model taxa, aquatic fungi, due to the lack of a suitable emoji. Coincidentally, aquatic fungi are one of the most neglected taxa in biodiversity conservation globally.[26] This suggests we need more diverse and inclusive emoji sets to ensure that all taxa receive equitable representation in digital communication tools. However, this can be a challenging task given that the key criteria evaluated for a new emoji to be added include a high frequency of use (https://unicode.org/emoji/proposals.html; criterion B.1). Unfortunately, organisms belonging to unpopular taxa (see,

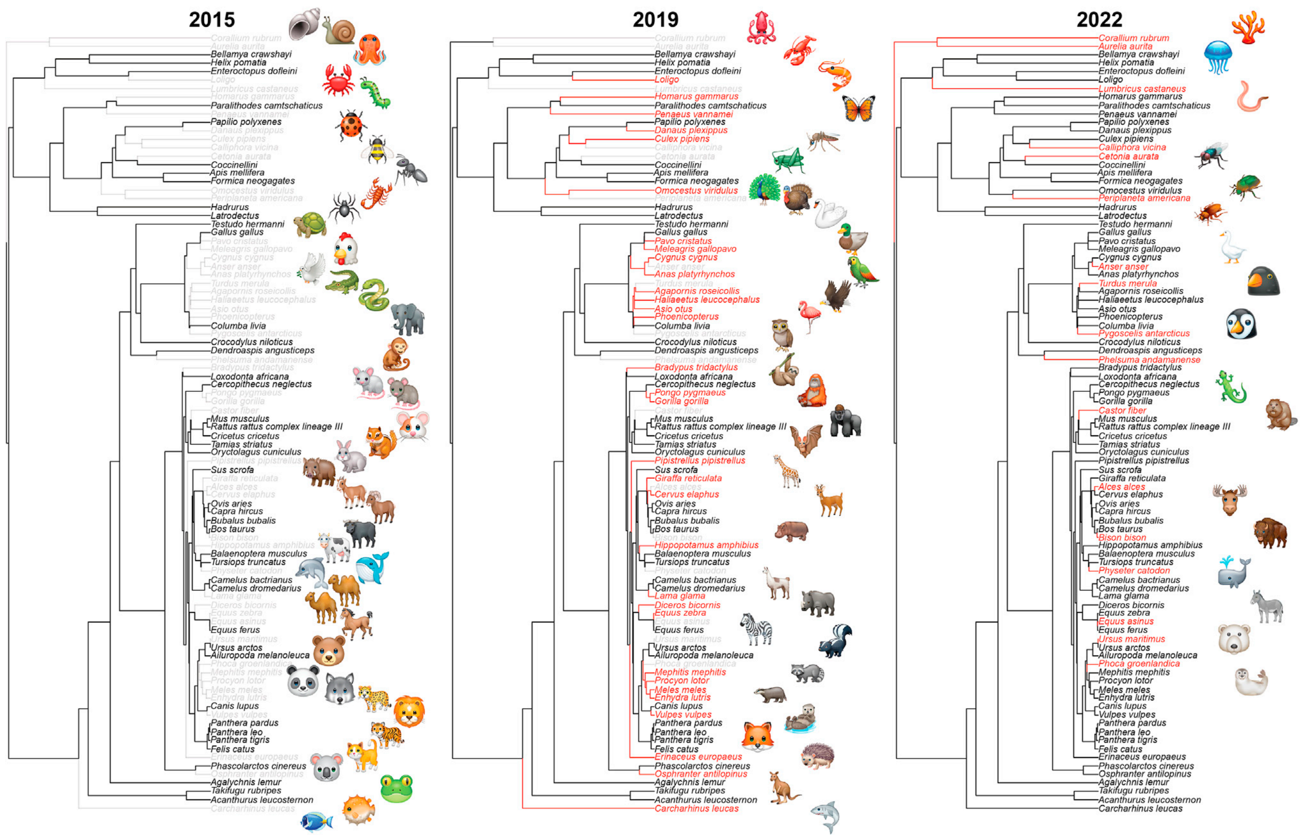


**Figure 3. Phylogenetic trees of emojis available in 2015, 2019, and 2022**

Black branches indicate available emojis at a given time step; red branches indicate emojis added from the previous time step; emojis that were added in the following time steps are in light gray.

e.g., Wong & Rosindell[28]), are rarely searched online, and the situation is even worse as some of them lack frequently used common names.[20] In fact, the common names of animal phyla not represented in the current emoji set generally have low usage levels (Table S2). Despite understandable, this rule can be problematic, as it risks hampering the extension of emojis in order to better cover the actual biodiversity of our planet. Nevertheless, several phyla nearly met the usage level of currently used emojis. Some keywords such as "sea star"/"starfish" (echinoderms), "water bear" (tardigrades), and "tenia" (flatworms), can potentially be good candidates for the inclusion of neglected animal phyla among current emojis (Table S2). Their inclusion would allow a better representation of the biodiversity of poorly considered taxa (e.g., the small animals belonging to the so-called "meiofauna", such as tardigrades), of key environments such as the seafloor, and the complex interactions between animals and human health.

On a more positive note, our analysis hints that things are moving forward precisely in this direction. The number of different animals represented by emoji more than doubled from 2015 to 2022, resulting in an increased representation of the overall phylogenetic diversity. In 2015, only three phyla were represented (chordates, arthropods, and molluscs) (Figure 3). The overall coverage of animal biodiversity remained rather constant until 2020, when annelids were added with just an emoji (an emoji named "worm" that most likely represents an earthworm), and further increased in 2021 when cnidarians were added with an emoji representing a red coral (Figure 3). This increase in phylogenetic diversity driven by less known taxa emphasizes a positive trend of enhanced opportunities for emojifying biodiversity communication, allowing users of digital platforms to discuss a range of biodiversity-related topics and sentiments more effectively, beyond the icons depicting iconic species.[29]

It must be pointed out that our study does not delve deeper into how users employ nature-related emojis in online discussions of biodiversity and conservation. However, we noticed that biodiversity and conservation topics are virtually never mentioned in the "Emoji Meaning" section of Emojipedia — note that emoji definitions on Emojipedia are researched and written by in-house lexicographers and only capture the main uses of each emoji. For example, Emojipedia clarifies that the snail and turtle emojis are often used to represent various senses of slowness, but apparently not to discuss the number of endangered species in both groups.[30–32] Even well-known flagship species for conservation, such as the giant panda or the tiger[33] are not, according to Emojipedia, used to discuss conservation topics. For example, the panda emoji is "[ …] often used with an affectionate tone and in association with China, where the animal is found". Exploring the uses of nature-related emojis in the context of biodiversity communication and conservation could be a topic for further research. This could be achieved, for example, through online surveys of emoji users or content analyses of social media posts.

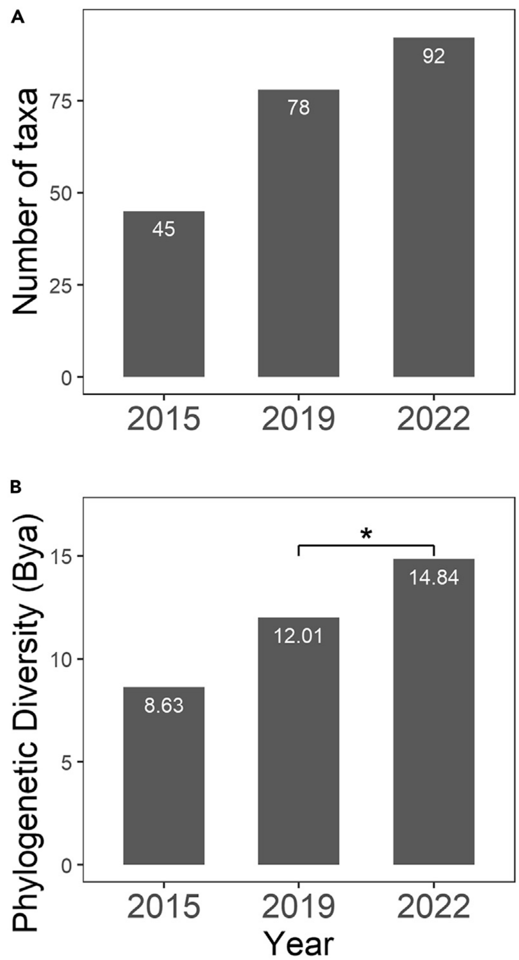


**Figure 4. Changes in the number of taxa and phylogenetic diversity of animal emojis**

Increase in the number of taxa (A) and in phylogenetic diversity (B) represented by animal emojis from 2015 to 2022. The asterisk in (B) indicates that, between 2019 and 2022, phylogenetic diversity increased more than expected on the basis of the number of taxa added between the two time steps.

The currently available set of nature-related emojis provides a broad but incomplete representation of the Earth's tree of life. The main biases pertain to the scarcity of emojis depicting fungi, plants, and microorganisms, and an overrepresentation of vertebrates over arthropods. While these disparities may reflect the general awareness of the public on biodiversity, in the long run, they can impede communication on environmental issues. However, we have highlighted a positive temporal trend, with the recent addition of emojis depicting neglected groups such as cnidarians and annelids. If this trend continues, we may soon reach a more equitable representation of the Earth's tree of life in the emoji set available across different online platforms, paving the way for a more engaging communication of biodiversity and its conservation. While the biodiversity crisis may seem distant from the online world, in our increasingly digitized society, we should not underestimate the potential of emojis to raise awareness and foster appreciation for the diversity of life on Earth.

## Limitations of the study

There are a few caveats that need to be borne in mind when interpreting our study. Foremost, in our study, we primarily focused on categorizing and mapping emojis related to nature and biodiversity. However, we did not delve into how people actually use these emojis in various communication contexts. Understanding the nuances of emoji usage, including the emotions, messages, or cultural factors they represent, is an important aspect that could provide deeper insights into their role in digital communication. Second, to classify emojis into taxonomic categories, we relied on their similarity to extant species. While this approach was informative, it is important to acknowledge that some emojis may not have direct equivalents in the natural world, leading to uncertain or questionable attributions. This limitation may affect the accuracy of our taxonomic classifications and their relevance to biological diversity. Last, our classification of emoji taxonomy was specific to the icons available on WhatsApp, a popular messaging platform. However, it is important to recognize that emoji sets vary across different platforms and may change over time. Therefore, the taxonomy we established may not be universally applicable, as other platforms may feature different emojis or use alternate criteria for classification.

## STAR★METHODS

Detailed methods are provided in the online version of this paper and include the following:



## SUPPLEMENTAL INFORMATION

Supplemental information can be found online at https://doi.org/10.1016/j.isci.2023.108569.

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## AUTHOR CONTRIBUTIONS

S.M. and G.F.F. conceived the idea. S.M. and G.F.F. collected data from Emojipedia. M.F. and G.F.F. carried out analyses. M.F. and S.M. prepared figures. All authors contributed to the writing.

## DECLARATION OF INTERESTS

The authors declare no competing interests.

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## STAR★METHODS

### KEY RESOURCES TABLE

| REAGENT or RESOURCE | SOURCE | IDENTIFIER |
|---|---|---|
| Software and algorithms | | |
| R-4.2.3 | R Core Team | https://www.R-project.org/ |
| Other | | |
| Data generated from this work (dataset with emojis information and Emoji Tree of Life) | This paper | https://doi.org/10.6084/m9.figshare.24213183 |

### RESOURCE AVAILABILITY

#### Lead contact

Further information and requests should be directed to the lead contact, Mattia Falaschi (matt_fala@hotmail.it).

#### Materials availability

The study did not generate new materials.

#### Data and code availability

- All the data used in this work is publicly available at Figshare: https://doi.org/10.6084/m9.figshare.24213183.
- The R code used to run the analyses and create plots is publicly available at Figshare: https://doi.org/10.6084/m9.figshare.24213183.
- Any additional information required to replicate the analyses is available from the lead contact upon request.

### METHOD DETAILS

#### Classification of emoji

We sourced emojis from the "Animals & Nature" section of Emojipedia (https://emojipedia.org/; Accessed on 4 May 2023). Emojipedia is a curated repository of emojis, providing up-to-date information on available emojis across multiple platforms (e.g., X, Facebook, WhatsApp, Skype, Apple). It provides the official emoji names sourced from the Unicode Standard and general information about each emoji's history and meaning.

We classified emojis depicting animals, plants, fungi, and bacteria into binomial species names. We also extracted the year in which any given emoji was approved as part of Emoji 1.0. We excluded emojis depicting extinct species (e.g., Dodos and *Tyrannosaurs*), fantastic animals (e.g., unicorn), and edible fruits and vegetables listed in the section "Food & Drink" of Emojipedia. We also excluded all human-related emojis (although *Homo sapiens* is a species, humans-related emojis are usually used in contexts very different from biodiversity communication). Given that different platforms may provide different pictures for a given emoji, we standardize species-level assignment based on the icon of WhatsApp, which is the most used messaging app globally (>2 billion users across 180 countries; https://www.statista.com/statistics/260819/number-of-monthly-active-whatsapp-users/). When we were uncertain about the attribution of a specific epithet, we assigned the name of the most common species resembling the icon (sometimes in consultation with experts; see "Acknowledgments"). In several cases, emoji were very generic representations of high-level taxa (e.g., "turtle", "spider", "ant", fish", "bird"). If just one emoji was available for that monophyletic taxon (e.g., "turtle", "spider", "ant"), we selected a widespread species belonging to that taxon and that was included in in the TimeTree database.[34] In this case, selecting a random species within the taxon would not affect biodiversity estimates, as all the taxa belonging to that taxon share the same evolutionary distance from the remaining animals. Two emoji ("fish" and "bird") provide very generic representations of taxa for which several other, better-characterized species are available. These emoji were excluded from biodiversity estimates. When variants of the same emoji were listed in Emojipedia (e.g., Monkey *versus* Monkey Face *versus* See/Hear/Speak-No-Evil Monkey; the wolf *versus* the dog), we only included one in the database.

Given the limited representation of non-animal emoji in the dataset (Figure 2A), we restricted in-depth analyses to animals.

### QUANTIFICATION AND STATISTICAL ANALYSIS

#### Emoji coverage of extant animal biodiversity

To assess to what extent emoji are representative of extant animal biodiversity, we compared the number of emoji per phylum with the number of described species. We obtained estimates of extant species by reign from the IUCN summary statistics (https://www.iucnredlist.org/resources/summary-statistics; version 2022-12-08). We obtained estimates of extant species by phylum from Scholl and Wiens.[35] Sholl & Wiens[35] do not provide the number of species for Annelida; thus, for annelids, we used estimates in Zhang.[36] We used Pearson's $\chi^2$ to assess whether the number of emoji was different from the number expected based on the taxonomic richness of different taxa. The analysis of residuals of cells in the contingency tables allowed us to identify the taxa for which there were more or less emojis than expected.[37] We excluded phyla with <10,000 described species from this analysis,[35] since none of these phyla showed to have associated emojis, and because below this threshold the expected number of emojis per phylum is < 1 (see Table S1). Furthermore, to test whether the taxonomic bias of emojis is similar to the one typically present in biodiversity analyses, we compared the number of emojis per phylum to what is expected on the basis of the number of species assessed by the IUCN redlist (www.iucnredlist.org; assessed on the 2nd of October 2023). We used a $\chi^2$ test to compare the observed and expected number of emoji species.

## Constructing an emoji tree of life

We used the list of emoji depicting animal species to construct an emoji tree of life to measure the increase in taxonomic diversity of emoji through time. For this, we used TimeTree 5.0,[34] a public knowledge base for information on the tree of life and its evolutionary timescale. We generated a tree for each of three time frames: 2015 (the year in which a large fraction of emoji was first approved in Emoji 1.0), 2019, and 2022. We used a null modeling approach[38] to test whether the increase in phylogenetic diversity over time was higher than expected by chance based on the increase in the number of present taxa. Null modeling is an analytical technique to assess the significance of observed patterns or relationships ("observed values") by comparing them to random expectations ("null distribution"). The main idea behind null modeling is to create a baseline or reference against which observed data can be compared to determine if the patterns or relationships are statistically significant or if they could have occurred by chance. We considered as observed values the set of emojis at three time steps (2015, 2019, 2022), for which we calculated the phylogenetic diversity (Faith's PD[39]) by assuming the diversity of species at each time step to be the equivalent of an "ecological community". Next, we generated null distributions by randomising 9999 times the composition of emojis based on the species present in 2019 phylogeny for the 2015–2019 comparison and on species present in 2022 for the 2019–2022 comparison. Note that we only performed two comparisons, instead of comparing all the consecutive years, because the annual increase in emoji species was low (average: 6.7 species per year), and such small differences heavily limit statistical power. After the randomisations, we compared the observed values and null distributions by calculating standard effect sizes (SES)[40,41] and associated significance (through two-tailed tests), whereby positive SES values indicate that the increase in phylogenetic diversity is smaller than expected by chance and vice versa. We ran null models using the "ses.pd" function from the R package picante.[42]