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ORIGINAL RESEARCH

Measuring human-nature interactions across digital platforms—an example from Israeli wildflowers

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Abstract

Human-nature interactions are ubiquitous and are commonly represented in the digital realm. Here, we aim to harness the rapidly accumulating wealth of new digital data sources and demonstrate that using multiple digital sources can help better understand societal aspects of biodiversity conservation. We explored different digital data platforms, including social media platforms, search engines, online encyclopedias, popular media articles, large online scientific databases, and citizen science platforms. These sources can represent different types of engagement people have with nature by different sectors of society. We assessed and compared the salience of 53 wildflower species in Israel across these digital sources as a test case. We found that different digital platforms highlight different species. Importantly, different platforms focused differently on a) narrow versus wide-ranging species, b) species found in locations that are closer or further away from roads, c) different plant growth forms, d) protected versus non-protected species, and e) endangered versus non-endangered species. These results suggest people have different engagements with nature, in different locations, across different digital data sources. We further show different relationships between salience across the different platforms. For example, the social media platform Flickr highlights unique species not represented in any other platform. Overall, our exploration of digital salience towards wildflowers in Israel demonstrates the importance of analysing multiple digital sources to allow for a more inclusive representation of the public and to better reflect species' cultural importance online.

Keywords Conservation culturomics · Flickr · Google · Human-nature interactions · iNaturalist · Wikipedia

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Introduction

The *Information age* offers new prospects for science to explore patterns at scales unimaginable until recently (Bollier and Firestone 2010; Ladle et al. 2016; Theocharis and Jungherr 2021). One such rapidly expanding field is culturomics - a form of computational lexicology that studies human behaviour and cultural trends through the quantitative analysis of digitised texts, images, videos, and sounds (Correia et al. 2021a; Albuquerque et al. 2023). This new field aims to better understand various facets of human cultures and behaviours by exploring the imprints different people leave when using search engines, social media sources, online encyclopaedias, and other digital platforms (any other website such as blogs, popular media, etc.). Conservation culturomics explores human-nature interactions as these are manifested in the ever-expanding digital realm to promote conservation (Ladle et al. 2016; Correia et al. 2021b). However, the comprehensiveness and coherence of such insights from different digital platforms are still unclear.

In recent years, conservation research using culturomic tools and approaches has grown in popularity (Correia et al. 2021b). In addition, social media platforms have become a known method for evaluating Cultural Ecosystem Services (Cheng et al. 2019). For example, social media photos have been used to evaluate charismatic animals and plants in Africa, assess the attractiveness of different nature reserves, and quantify reserves' cultural services and benefits (Willemen et al. 2015). Culturomic tools have also been used to assess interest in specific species. For example, Correia et al. (2016) used internet saliency (number of web pages containing a species name) to compare national and international interest in Brazilian birds. Further, Millard et al. (2021) used Wikipedia page views to construct an awareness index to evaluate changes in people's awareness of different species.

Digital sources of human-nature interactions are varied and can include social media platforms, search engine visitation metrics, online encyclopedias, popular news media publications, scientific databases, and citizen science reports. Different platforms can appeal to different people (Cooper et al. 2019), and their content may represent different levels of interactions, from basic interactions (for example, seeing plant species in the background of photos) to interest (for example, reading about a species in Wikipedia) and deeper levels of engagement (for example, reporting a sighting of a species online; Correia et al. 2021a, b; Vardi, et al. 2021b). Culturomic content further represents both documentation of first-hand (positive or negative) interactions with nature, for example, uploading photos and videos of yourself in nature, and indirect interactions—experiencing nature through a medium such as watching videos/photos of natural elements. People may further highlight different species' features (e.g., size, distribution, taxonomic group) across different platforms (Correia et al. 2021a, b). Thus, to consider various types of human-nature interactions, scientists need to explore them across multiple digital sources (Cooper et al. 2019; Hartmann et al. 2022; Vardi, et al. 2021b).

Species digital salience, how often their names are searched for or mentioned on an online platform, can be used to measure the level of public interest in these species (Correia et al. 2016; Mittermeier et al. 2021). Evaluating salience across multiple platforms can account for various types of human-nature interactions, and hopefully represent more sectors of society that use different online platforms (Duggan and Brenner 2013; Ghermandi and Sinclair 2019). For example, Vardi et al. (2021b) showed that even though plant species had similar salience in Google and Wikipedia, the two sources highlighted different species

and traits, and people may use the two platforms for different reasons of interest in nature. Acknowledging societal inequalities in representation and access to information is also key for culturomics research. Combining data from different digital platforms may allow a more comprehensive representation of species in the digital realm by different people and cultures, though Internet access and representation biases may still persist.

Here, we compared Israeli wildflower species popularity across different types of online platforms. We further explored how species' popularity is affected by different attributes of the species, such as its protection by law, its distribution, and accessibility to its blooming grounds. Overall, plant conservation receives less attention compared to animal conservation (Balding and Williams 2016). This is despite the fact that plants are key elements in ecosystems globally and are encountered by most people daily (Kowarik et al. 2011; Palliwoda et al. 2017). Furthermore, many plant species have great cultural significance across societies (Wedel 2017). In Israel, a nationwide education campaign in the 70s managed to achieve a cultural change in Israeli society, encouraging positive human-plant interaction and a great appreciation of seasonal blooms (Regev 1993). With this rich history, Israeli wildflowers are the subject of much online interest and there are designated websites reporting on blooming locations and timing. In our work, we aimed to demonstrate the usefulness and importance of exploring multiple digital sources to evaluate species online prevalence in people's lives in the hope of a more representative sampling of society.

Methods

Israeli wildflowers and society

Israel enjoys bountiful flora due to its climate and geographic location (Alon 1990). There are over 2,500 wild plant species in Israel, of which 300 are protected by law and 150 are endemic. These species represent over 130 different families (Danin 2004), and are diverse in colour, shape, growth rate, and habitats (Alon 1992). Israel's biodiversity has been intertwined with the country's rich history, receiving many biblical mentions, and inspiring much poetry and art (Roll et al. 2009), and seasonal blooms being widely celebrated across the country (Shachak 2015). A successful nationwide campaign to prevent wildflower picking (flowers that grow in the wild), which dates back to the 1970 s (Regev 1993), has left wildflower picking uncommon throughout the country. Israeli wildflowers are also the subject of much online interest (Vardi, et al. 2021b) and there are several designated websites to report blooming locations and timings (see below). As such, Israeli plants can provide an excellent case study to explore digital human-nature interactions. However, many species may not be represented online at all and thus cannot be part of such analyses (Correia et al. 2021a, b; Vardi et al. 2021b).

Israel's society is diverse and includes disparities between its different sectors. This is an important point to consider when conducting a culturomics analysis to acknowledge which parts of the public the data represent (Ghermandi and Sinclair 2019; Vardi, et al. 2021b). A total of 8.2% of the population in the country does not use the internet at all (Israel Central Bureau of Statistics 2023). Israeli society also includes secular and religious people; Jews, Arabs of both Muslim and Christian faiths, and Druze, which can translate to different online representations. For example, more secular than ultra-orthodox Jews use the Internet

(92% compared with 64% respectively), and younger people (20-64) use it more than older (65+) people (95% compared with 79%, respectively). But there are also similar trends, for example, Jews and Arabs, as well as men and women, use social media to a similar extent (Israel Central Bureau of Statistics 2021).

Salience data

We compared digital interest and blooming reports of 53 wild plant species in Israel (see Table S1 and S2). These included the top 50 most popular annual and geophytes on Wikipedia and Google (Vardi et al. 2021b; excluding four species, see Table S1) plus other wild iris species in Israel (excluding two species, see Table S1). We evaluated interest in these species across several digital platforms. We explored the following culturomic sources: Flickr - a photo-sharing social media platform; Google search engine; popular media - articles mentioning wildflowers concerning nature conservation, travelling advice, or health-related issues in two prominent Israeli news outlets; and Wikipedia—the Hebrew edition of the online encyclopedia. We explored these additional digital data sources: BioGIS—a national scientific database repository that includes blooming observations and specimens; iNaturalist—a global citizen science platform where private people can report their species observations that are later verified by other users; and two other Israeli sources dedicated to reporting wildflower blooms that share attributes of both social media and citizen science platforms (see Table S3 for links of all sources). The first, 'Rotem', is targeted more at professionals or dedicated amateurs reporting plant locations and bloom periods and is thus more similar to classical citizen science platforms (hereafter referred to as citizen science; see Table S3). The second, 'Tiuli', is a website geared toward travel where people share their experiences and recommendations, thus more akin to a classical social media platform (hereafter referred to as social media). The different platforms represent different types of interaction with nature, from (potentially) strictly digital (e.g., Google, Wikipedia, popular media), to documented physical encounters with the species (e.g., citizen science, social media posts). They further represent different scopes—from local to global, as well as different audiences—from scientists (BioGIS) to nature enthusiasts (citizen science), and the general public (Google, popular media, social media, and Wikipedia). The specific platforms chosen were partly based on familiarity with popular local platforms, and partly due to data-accessibility restrictions (see discussion for limitations). The different platforms also differ from one another in their purpose and targeted audience, particularly age and gender (See Fig. S1). While the data for Flickr, iNaturalist, and Google are global and not strictly representative of Israeli users, these data highlight the potential of better representation of the general public when considering multiple data sources.

For each species, we collected their salience across the different digital sources (see Fig. 1). Data extraction was conducted in October 2021 for all sources but popular media for which data extractions was conducted in October 2023, Data were explored until the end of 2020 and was limited in the starting date by the availability and accessibility of each platform. Data from Flickr were collected using the R package 'photosearcher' (from January 1, 2005, until December 31, 2020; https://github.com/ropensci/photosearcher; (Fox et al. 2020). We searched for photos tagged or described with the species' scientific or Hebrew name and then excluded results geotagged outside of Israel. All these results included referrals to the relevant species' name, irrespective of whether the images correctly displayed

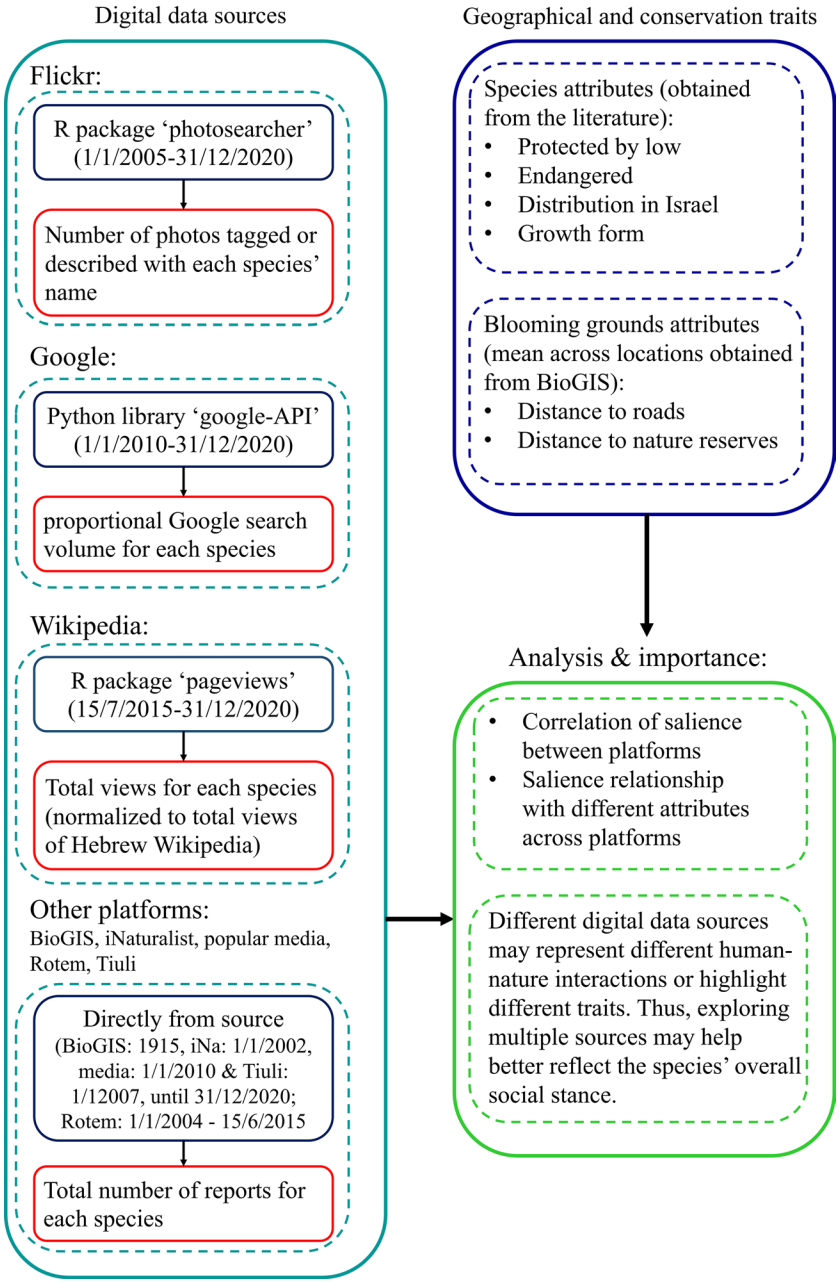

Fig. 1 A flowchart of the methodology of our exploration of interest in Israeli wildflowers in various digital sources. On the left, we elaborate the different data mining procedures employed to obtain the data from each of the sources we analysed and the dates for which data was collected. On the top right side, we list the biological and cultural traits we obtained for each species, and on the bottom right, the analyses we conducted and the reasoning and importance of exploring multiple digital sources in unison

it. We considered all of these results from Flickr, even potentially erroneous identifications of species, as these still indicate the cultural value of the species mentioned in the eye of the uploader (even if they cannot properly identify it). This is also true when the image is not of a wild plant but rather its representation in art or other cultural products (Baudrillard 1994). We obtained the proportional weekly Google search volume in Israel from January 1, 2010, until December 31, 2020, relative to all Google searches in Israel during that period. Google is the most used search engine and the top visited website in the country (https://www.similarweb.com/). Google search volumes were obtained using the Google health trends API (application program interface) and a dedicated Python library (Python version 3.8; google-API-python-client; https://pypi.org/project/google-api-python-client/; for full details, see (Vardi et al. 2021b). We used Google topics to include results across all searches made with synonyms, typos, and similar or related terms across languages (for example, Hebrew and English common names, and species scientific names) related to the species name (Cooper et al. 2019). We downloaded all records from BioGIS (dates back to 1915) and all research-grade observations of the species reported to iNaturalist (from January 1, 2002, until December 31, 2020) based on their scientific names. Blooming reports recorded in the local citizen science platform - Rotem (January 1, 2004, until June 15, 2013; afterwards, data were no longer available) and in the local social media platform - Tiuli (starting from January 1, 2007, until December 31, 2020) were downloaded directly from these sources' websites (Table S3) based on the species' Hebrew names. We obtained daily Wikipedia page views with the R package 'pageviews' (Keyes and Lewis 2016) from July 15, 2015, until December 31, 2020. Wikipedia is the 7th most visited website in Israel (https://www.similarweb.com/) and The Hebrew version is mostly accessed from within Israel (88%; Zachte 2018). We retrieved the number of entries for each species page in the Hebrew edition made from all devices by human users. To control for differences that may have been caused due to the different time periods of available data from each source, we repeated our analysis by comparing interest from BioGIS, Flickr, Google, iNaturalist,, and Tiuli limited to the same time frame of January 1, 2010, until December 31, 2020.

For each species, we further recorded its prevalence in the Israeli news media (see Table S2) by searching the Hebrew name of the species in the internal search platforms of two popular Israeli news media outlets—Haaretz and Ynet (see Table S3) and tallying relevant results (articles regarding nature conservation, travelling advice, and health advice) from January 1, 2010 until December 31 2020. The Haaretz website is ranked the 17th most popular website in Israel (https://www.similarweb.com/). It is commonly associated with the political left, and a survey in 2011 showed that 84% of the public perceived the paper as left-wing. Ynet is the most popular news website and is ranked 4th most popular website in Israel. While less associated with a political stand, 63% of the public perceived it as left oriented outlet (https://b.walla.co.il/item/1882308).

Geographic data and conservation traits

Beyond species observations and records, BioGIS provides geographic information regarding nature reserves, roads, and human settlements in Israel which we further analysed. For each species known blooming ground recorded in BioGIS, we collected its distance from the nearest nature reserve, and distance to the nearest road or closest settlement as a measure of accessibility and human interference. We averaged these traits per species across all its

blooming grounds to obtain a single value of each distance assessment per species. From the literature, we tallied the number of different regions in Israel the species is found in for an estimation of how widely distributed the species is (Feinbrun-Dotan and Danin, 1998). We followed the fine-grain division of 27 biogeographical regions of Israel based on climate, geology, and vegetation following Danin 2004. For each species, we noted whether they are protected by Israeli law and whether they are considered locally endangered (data obtained from Fragman et al. 1999; Shmida and Pollak 2007). We further distinguished between two plant growth forms—annuals, which complete their life cycle within a single season, and geophytes, which are perennial plants with an underground storage organ allowing them to survive harsh conditions and regrow when conditions become favourable (see Table S2 for all these values per species). These traits allowed us to test how accessibility (distance to road, nature reserves, and settlements), conservation status (endangered status and protection by law), and encounter rates (annuals vs geophytes) affect species salience across the different platforms.

Statistical analysis

We used the Wilcoxon test to compare salience across the different digital platforms between annuals and geophytes, species protected by law and unprotected species, and endangered and not-at-risk species. We further tested for correlations between the different digital sources and the different geographic attributes of the flower blooming grounds - mean distance to road and mean distance to nature reserves, using Kendall's rank correlation tau (Hollander and Wolfe 1973). We did not include distance to settlements due to its high correlation with the other attributes. We also tested the correlation between species salience and their prevalence across Israel - the number of regions the species grows in. We used the false discovery rate to correct for multiple testing (Benjamini and Hochberg 1995). We converted all our salience measures (per data source) into proportions to enable comparisons across sources with different salience scales. The species with the highest value obtained in each platform was assigned as 1, and other species' salience values were proportions of this. All analyses were conducted in R version 4.1.2 (2017). We repeated all analyses once for all data sources and timelines, and once for the data during 2010-2020 from those sources that had data throughout this period (BioGIS, Flickr, Google, iNaturalist, Popular media, and Tiuli).

Results

Overall salience

Overall, species received different levels of attention, with some not having any records or mentions in Flickr, the popular media, and Tiuli, and others receiving up to 1660 photos on Flickr (*Daucus carota*), 40 relevant media articles (*Iris atropurpurea*; see Table S2), and 358 reports in Tiuli (*Anemone coronaria*). We found that different digital platforms emphasised different species (Table S2). The top 10 most popular species partly overlapped across sources, with *Anemone coronaria* being in the top 10 in seven out of the eight sources we explored, and ranking first in three of them (Table 1).While most species appeared in the

Table 1 Specia appearing in the top 10 most popular across all platforms and their overall total salience and mean ranked across all platforms. The table also includes the growth form (Geophyte or Annual) for each species and whether they are endangered (1 for yes) and protected by law. Photos taken from https://commons.wikimedia.org/ with authors named in the table

Species	Photo	Photo by	Times in top 10	Platforms	Total salience	Mean rank	Growth Form	Endangered	Protected
Anemone coronaria		Jim Evans	7	BioGIS, Google, iNaturalist, Popular media, Rotem, Tiuli,	162934.5	0.7175	G	0	1
Cyclamen persicum		Muhammad Musa Shawan	6	BioGIS, iNaturalist, Popular media, Rotem, Tiuli, Wikipedia	54400	0.575	G	0	1
Silybum marianum		Matankic	6	BioGIS, Google, iNaturalist, Popular media, Wikipedia, Flickr	106376.5	0.33375	A	0	0
Drimia maritima		Javier martin	4	BioGIS, Rotem, Tiuli, Wikipedia	102375.5	0.34375	G	0	1
Daucus carota		User:Tigerente	4	BioGIS, Google, iNaturalist, Flickr	41207.5	0.29125	A	0	0
Narcissus tazetta		Ariesaada	3	iNaturalist, Rotem, Tiuli	23557.5	0.33	G	0	1
Colchicum stevenii		Gideon Pisanty	3	iNaturalist, Popular media, Rotem	21506.5	0.28375	G	0	1
Tulipa agenensis		Zachi Evenor & MathKnight	3	Popular media, Rotem, Tiuli	17422.5	0.23625	G	0	1
Lilium candidum		Arielinson	3	Google, Popular media, Wikipedia	127443	0.23	G	1	1
Sternbergia clusiana		Gideon Pisanty	3	Google, Rotem, Tiuli	35251.5	0.2225	A	0	1
Portulaca oleracea		ZooFari	3	Google, Wikipedia, Flickr	80161	0.2125	A	0	0
Chrysanthemum coronarium		MathKnight & Zachi Evenor	3	BioGIS, iNaturalist, Wikipedia	41048.5	0.21	A	0	0
Lupinus pilosus		Zachi Evenor	3	iNaturalist, Popular media, Tiuli	36339.5	0.20375	A	0	1
Pancratium maritimum		Talia Lavi	3	Popular media, Wikipedia, Flickr	50289	0.19875	G	0	1
Ranunculus asiaticus		Tamar HaYarde	2	BioGIS, iNaturalist	20071.5	0.28125	G	0	1
Anagallis arvensis		H. Zell	2	BioGIS, Flickr	34374.5	0.255	A	0	0
Iris atropurpurea		pintal	2	Popular media, Tiuli	40623.5	0.24625	G	1	1
Gynandriris sisyrinchium		Nanosanchez	2	BioGIS, iNaturalist	11756.5	0.22125	G	0	0
Eruca sativa		Alvesgaspar	2	Google, Wikipedia	175917	0.1975	A	0	0
Crocus hyemalis		Dror Feitelson	2	Rotem, Tiuli	12244.5	0.1775	G	0	1
Iris haynei		Israel Hirschber	2	Google, Popular media	42439	0.16	G	1	1
Oxalis pes-caprae		MathKnight & Zachi Evenor	2	Wikipedia, Flickr	37808.5	0.12875	G	0	0
Orchis papilionacea		MathKnight	1	Rotem	8693	0.17125	G	0	1
Scilla autumnalis		Ophrys34	1	Rotem	5808	0.14875	G	0	0
Iris palaestina		Gideon Pisanty	1	Tiuli	7121	0.13	G	0	1
Iris pseudacorus		Stahlkocher	1	Flickr	7473.5	0.12625	G	1	1
Ophrys apifera		BerndH	1	Flickr	9052.5	0.125	G	0	1
Lamium amplexicaule		Eugene Zelenko	1	Flickr	6549.5	0.12375	A	0	0
Linum pubescens		Zachi Evenor	1	BioGIS	10444.5	0.12125	A	0	0
Convolvulus arvensis		4028mdk09	1	Flickr	13589	0.1125	A	0	0
Scolymus maculatus		Iorsh	1	Google	30947.5	0.1075	A	0	0
Allium ampeloprasum		Javier martin	1	Google	56299.5	0.1075	G	0	1

top 10 in at least two sources, some species were highlighted by only one platform. For example, *Allium ampeloprasum* was ranked 4h in Google but did not appear in the top 10 of any other data sources. Similarly, *Iris palaestina* only appeared in Tiuli's top 10. Flickr was the only data source that had four unique species in its top 10 that did not appear in any other platform' top 10 (*Ophrys apifera*, *Iris pseudacorus*, *Convolvulus arvensis*, and *Lamium amplexicaule*). The two local platforms, Rotem and Tiuli, shared 7 species in their top 10 (though in different order), as did BioGIS and iNaturalist (Table 1).

We found that popular media, the local citizen science platform Rotem, and the local social media platform Tiuli, had greater salience for geophytes than annuals (Fig. 2; Table

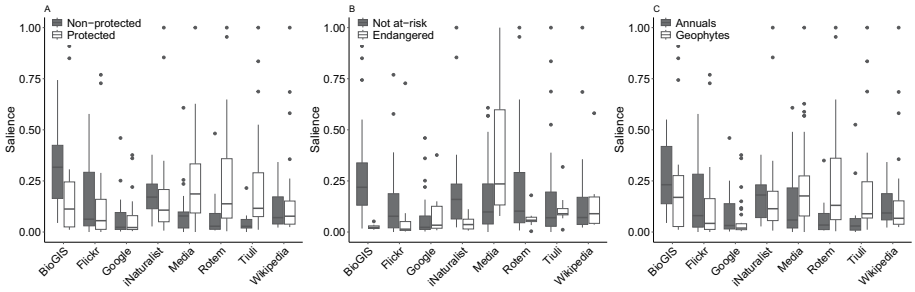

Fig. 2 Attributes of species compared to their salience across digital platforms. Plant species' (N = 53) salience is displayed as proportions of the highest value in each platform. Displayed are links between salience and (**A**) species' protection status by the Israeli law (protected or not), showing median interquartile range in boxes, and dots as outliers; (**B**) species' endangered status (endangered or not-at-risk); and (**C**) growth form—annual or geophyte

S4). These three platforms also highlighted protected species more than non-protected species. BioGIS showed the opposite result emphasising non-protected species more than protected species (Fig. 2, Table S4), though this difference disappears when considering observations only from 2010 onwards (Fig. S2). The classical culturomic sources (Flickr, Google, and Wikipedia) and the global citizen science platform iNaturalist show similar popularity values to both growth forms and protected and non-protected species. We again found contrasting results when exploring interest in endangered species versus those not at risk. BioGIS and iNaturalist significantly highlight non-endangered species, with Flickr (and BioGIS data only from 2010-2020) showing a similar but non-significant trend. However, popular news media showed significantly more attention to endangered species (Fig. 2, Table S4). The remaining digital platforms (Google, Rotem, Tiuli, and Wikipedia) showed no differences in salience between endangered and non-endangered species. It is important to mention that within the list of species explored here, only irises are endangered (see Table S2).

Salience and geographical attributes

Our case study also emphasised the importance of human-nature interactions and natural elements outside nature reserves and protected areas (Dickinson and Hobbs 2017). For most data sources, we saw no relation between salience and distance to nature reserves (Fig. 3, Table S5). This pattern was observed across all data sources except the scientific repository BioGIS, where we found a significant increase in salience as the distance from reserves increased, though this trend became non-significant when we analysed data only from 2010-2020 (Fig. S2). Similarly, looking at salience as a function of distance to the nearest road, we found no clear trend for most sources. Salience in BioGIS increased as the distance from roads increased, though this trend disappeared when considering data only from 2010-2020 see (Fig. 3, Table S4). Finally, we found a rise in salience in BioGIS, iNaturalist, and Flickr (marginally significant for the latter) towards more widespread species (Fig. 3, Table S4). Popular news media showed the opposite trend (non-significant) and tend to highlight species with narrower distribution within Israel.

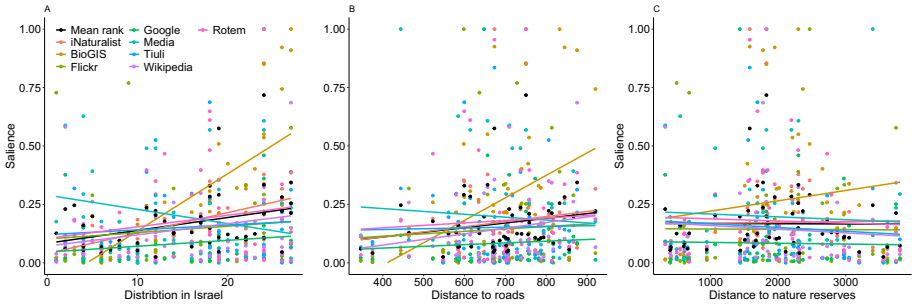

Fig. 3 Attributes of species compared to their salience across digital platforms. Plant species' (N = 53) salience is displayed as proportions of the highest value in each platform (rank). The mean rank across all platforms together is also plotted in black. Displayed are links between salience and (**A**) species' occurrence in Israel based on number of regions in Israel the species grows in (raw data in dots and overall trend in lines); (**B**) species' mean distance to the nearest road (meters); and (**C**) species mean distance to nature reserves

Correlations across sources

We found several significant positive correlations between salience across some of the different digital sources (Fig. S3). In our Israeli plant species exploration, we found that online popularity (species popularity ranking at each platform) positively correlates between scientific datasets, local and global citizen science, and local social media platforms (between BioGIS, iNaturalist, Rotem, and Tiuli; see Fig. S3). Salience in popular media was also positively correlated with local and global citizen science (iNaturalist and Rotem) and with the local social media platform of Tiuli. While salience in Wikipedia was positively correlated with all other platforms except Flickr, salience in Google was only correlated to Wikipedia, and salience in Flickr was not significantly correlated to any other data source (Fig. S3). When testing correlations between salience in six of the data sources (BioGIS, Flickr, Google, iNaturalist, popular media, and Tiuli) ranging over the same time period (2010-2020), we found similar results (Fig. S4).

Discussion

We present here an approach to explore in unison different digital sources (culturomic sources, citizen science platforms, and scientific repositories) to evaluate species' cultural significance online. Understanding this human element is essential for conservation efforts (Bennett et al. 2017) though very challenging to evaluate (Soriano-Redondo et al. 2017). The merits of using culturomics approaches to explore human-nature interactions by conservation scientists and practitioners have been previously shown (Correia et al. 2021a). We suggest that using various digital sources can further increase the value of culturomic studies for conservation and improve conclusions reached by representing more diverse groups of people. We highlight the value of exploring digital sources of different purposes (e.g., social media platforms, citizen science sources, online encyclopedias, etc.) and of different scopes (global and local). While biases and limitations persist (see below), a general assessment of people's interest in nature using relatively low-cost and readily accessible tools can

improve conservation efforts. For example, this can inform conservationists in selecting a local flagship species, benefiting from a species that already attracts attention from the public. We tested our approach using salience towards Israeli wildflowers across different digital sources. Our results highlight differences between different digital platforms potentially arising from the different platforms' types and purposes (e.g., search engine, encyclopedia, citizen science, etc.), as well as target audience.

Evaluating species salience across multiple sources can include nature interactions from different people—scientists, nature lovers, and the general public, as well as from different age groups and socioeconomic backgrounds (Duggan and Brenner 2013; Ghermandi and Sinclair 2019; Ghermandi et al. 2020; Vardi et al. 2021b). Specifically, social media data is more common among younger generations (Liu et al. 2016), though user age groups change across unique platforms (Ortiz-Ospina 2019). For example, 48% of older Americans (age 65+ who use the Internet) use Facebook, whereas only 4% and 6% use Instagram and Twitter, respectively (Duggan and Brenner 2013). By exploring several digital data sources simultaneously, we demonstrate that some biases can be reduced. Thus, future culturomics studies should aim at combining insights from different sources that may be used by different groups. Our case study exploring Israeli plant species demonstrated the value of exploring multiple digital sources in unison. While salience across many sources was positively correlated, demonstrating consistency in species popularity across platforms, few digital data sources stood out from the overall trend (Fig. 2 and 3, Fig. S3). We show that salience in Flickr highlights different species than other platforms and does not correlate to any other platform explored (Table 1, Fig. S3). Flickr is often used for cultural ecosystem services evaluations, partially due to its easy API access (Ghermandi and Sinclair 2019; Leppämäki et al. 2025). Our results suggest that conclusions based solely on Flicker may represent a particular facet of human-nature interactions and may not be fully inclusive. For example, Flicker's top three ranked flowers include two species not included in any of the other platforms' top 10 (Table 1 and S2). Hence, conclusions made using solely salience from Flickr would be partial and potentially not very representative of the public. Google search volume also seems to stand out from many other platforms (Fig. S3). Nevertheless, Google salience is positively correlated with Wikipedia, potentially as a consequence of people reaching Wikipedia from an initial Google search (McMahon et al. 2017; Segev and Sharon 2017). Beyond these, the significant positive relationships between the remaining sources indicate similarities in species' overall salience across different digital sources.

Nevertheless, when exploring geographical and conservation traits of our species, several sources highlighted subsets of species (Figs. 2 and 3). For example, we found that the scientific database we explored—BioGIS, focused much more on species found further away from reserves and roads. However, these results are weakened when considering data only from 2010-2020, potentially reflecting changing trends in scientific endeavours. BioGIS (full database and 2010-2020 database) also highlighted annual, non-protected and non-endangered species. This highlights that scientists may have different interests when they record species in online repositories from the interests of the general public (Roll et al. 2016). Culturomics approaches can help explore such gaps between scientific interest and public awareness. Popular news articles had greater emphasis on protected species and endangered species (Fig. 2). This is unsurprising as popular media often focuses more on extreme events, controversies, and topics that elicit strong responses from their readership—such as threatened species (McCombs and Shaw 1993; Veríssimo et al. 2014). These

results further stress the added value of exploring different platforms when exploring digital human-nature interactions. For example, local platforms (popular media, Rotem, and Tiuli) showed increased interest in protected vs non-protected species, whereas more global platforms (Flickr, Google, and iNaturalist) did not (Fig. 2, Table S3). This may highlight the importance of protected species to locals and demonstrate the importance of conservation policies and outreach. This may also be a cause for concern as the list of protected plant species in Israel was decided more than 40 years ago and has not been updated since. Decision makers can use our findings to advocate for the importance of species protection and the need to revise them to stay meaningful and gain benefits from their increased popularity.

Our results also emphasise the importance of human-nature interactions outside nature reserves and in modified landscapes. In most of our sources, salience was unaffected by the species' distribution degree of distance to roads or reserves (Fig. 3, Table S5). Beyond protecting nature, nature reserves represent a designated place for human-nature interactions (Roux et al. 2020). Indeed, human-nature interactions inside reserves were shown to be more meaningful and provide more Cultural Ecosystem Services than ones outside protected areas (Eastwood et al. 2016). However, interacting with nature is not limited to natural reserves. The ubiquitous presence of nature can strengthen people's connections to it, enhance its values in the general public's eye, and provide vast opportunities for human-nature interactions (Roll et al. 2021; Vardi et al. 2021a).

Conclusions

The value of plants as ambassadors of conservation in Israel was demonstrated in a campaign to prevent the construction of a new village in Northern Israel (Furst 2017). This village was planned to be built on Mount Gilboa, the global stronghold of the Gilboa iris (*Iris haynei*). This led to a successful national campaign against this development initiative to keep its natural habitat wild. This initiative was spearheaded by the Society for the Protection of Nature in Israel, the oldest and most prominent Israeli conservation non-governmental organisation, whose emblem is the Gilboa iris (Furst 2017; Regev 1993). Such examples demonstrate the cultural importance of plant species and how public awareness can be leveraged for conservation (Sagi 2020). Our analysis, quantifying wildflowers' digital interest, can help decision-makers highlight the importance of protecting wildflowers' blooming grounds. Conservation managers and practitioners can therefore use digital predictors of public engagement (salience, sentiment, and temporal trends) as tools to advocate for green spaces and natural areas, wildlife protection and conservation, and education towards sustainable behaviour and positive human-nature interactions. For example, we found that geophytes are significantly more popular than annual plants in several platforms (popular media, Rotem, and Tiuli; Fig. 2). In the future, if open spaces are in danger of destruction for anthropogenic development, raising awareness to geophytes that grow there might be deemed more successful than focusing on annual plants in the area.

While holding much promise, digital data also manifest various inherent biases and limitations (Jarić et al. 2020; Correia et al. 2021a). As mentioned, different genders and age groups engage differently with digital platforms, which supports the analysis of multiple sources to gain meaningful insights (see above). Some groups—such as indigenous people-are still much less represented in such digital exploration (Jarić et al. 2020; Correia et al.

2021a), yet should not be excluded from conservation discussions and policy (IPBES 2019). We aimed to include in our cross-platform explorations larger spans of society. Nevertheless, we acknowledge that explicit and implicit impediments in people's access to both nature and digital platforms are vast and may never be fully bridged. Beyond this, culturomics approaches also hold technological limitations and ethical considerations (Di Minin et al. 2021; Olteanu et al. 2019). Different online platforms allow different data accessibility for researchers, which can limit the scope of scientific explorations with respect to platforms explored (e.g., Flickr; Hartmann et al. 2022). In addition, transparency and replicability are recurring issues as companies change their data accessibility, metadata, and interfaces (Leppämäki et al. 2025). Furthermore, many of these sources only reflect trends of the past few years and are difficult to compare to studies of human-nature interactions from more classical sources such as surveys and literary analyses (Correia et al. 2021a). The platform's goal and affordances, such as the presence of discussion forums, uploading options, etc., can greatly determine the type of interaction users have with nature (Arts et al. 2021; Verploegen et al. 2021), thus dictating the digital imprints that can be explored. Still, culturomics approaches can provide valuable information and improve understanding of social aspects of conservation. When doing so, it is important to explore multiple digital sources, as we have shown, to allow a more inclusive sampling of society. We hope that similar approaches of combining multiple online platforms to evaluate species' overall digital prevalence to study human-nature interactions will be replicated across other taxa and in other regions. This could enable the creation of a global dataset of social aspects of biodiversity conservation across countries and cultures to aid conservation actions.

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Declarations

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