Article

Strengths and Challenges of Using iNaturalist in Plant Research with Focus on Data Quality

Eduard López-Guillén [1,†], Ileana Herrera [2,3,*,†], Badis Bensid [1,4], Carlos Gómez-Bellver [1], Neus Ibáñez [1], Pedro Jiménez-Mejías [5], Mario Mairal [6], Laura Mena-García [1], Neus Nualart [1], Mònica Utjés-Mascó [1] and Jordi López-Pujol [1,2,*]

1 Institut Botànic de Barcelona (IBB, CSIC-CMCNB), 08038 Barcelona, Spain;
   eduard.lopez.guillen@gmail.com (E.L.-G.); badis.bensid@autonoma.cat (B.B.);
   carlosmiguel.gomez@ibb.csic.es (C.G.-B.); nibanez@ibb.csic.es (N.I.); laura_santboi@hotmail.com (L.M.-G.);
   nnualart@ibb.csic.es (N.N.); monica.utjes@utma.eu (M.U.-M.)
2 Escuela de Ciencias Ambientales, Universidad Espíritu Santo (UEES), Samborondón 091650, Ecuador
3 Instituto Nacional de Biodiversidad (INABIO), Quito 170501, Ecuador
4 Departament de Biologia Animal, Biologia Vegetal i Ecologia, Facultat de Biociències,
   Universitat Autònoma de Barcelona, 08193 Bellaterra, Spain
5 Área de Botánica, Departamento de Biología Molecular e Ingeniería Bioquímica,
   Universidad Pablo de Olavide, 41013 Sevilla, Spain; pedro.jimenez@uam.es
6 Departamento de Biodiversidad, Ecología y Evolución (Unidad de Botánica), Facultad de Ciencias Biológicas,
   Universidad Complutense de Madrid, 28040 Madrid, Spain; mariomai@ucm.es
* Correspondence: herrera.ita@gmail.com (I.H.); jlopez@ibb.csic.es (J.L.-P.)
† These authors contributed equally to this work.

Abstract: iNaturalist defines itself as an "online social network of people sharing biodiversity information to help each other learn about nature" and it is likely one of the largest citizen science web portals in the world, as every year millions of observations across thousands of species are gathered and collectively compiled by an engaged community of nearly 3 million users (November 2023). The strengths and potentialities that explain the success of the platform are reviewed and include, among others, its usability and low technical requirements, immediacy, open-access, the possibility of interacting with other users, artificial-intelligence-aided identification, versatility and automatic incorporation of the validated records to GBIF. iNaturalist has, however, features that scientists need to carefully consider when using it for their research, making sure that the quality of observations does not limit or hinder its usefulness in plant research. While these are identified (e.g., the lack of representative photographs for many observations or the relatively frequent identification errors), we provide some suggestions to overcome them and, by doing so, improve the use and add value to iNaturalist for plant research.

Keywords: alien plants; citizen science; conservation; monitoring; species discovery; threatened species

1. Introduction

Citizen science, defined as the participation of amateur scientists in activities that contribute to scientific research [1–3], has been in place since the beginning of modern natural science [4]. For instance, amateur naturalists who created scientific collections in Europe even before the 18th century (particularly the so-called "cabinets of curiosities") helped to establish the foundation of botanical and zoological knowledge that is still used in the present day [5,6]. There are even examples of citizen science records that predate the creation of these collections, such as phenological data that have been recorded for centuries in Japan [3]. It can be stated, therefore, that the role of amateur scientists was already important in natural sciences in the past. Indeed, it was not until the late 19th century that being a scientist became a formal profession [4]. As a result, citizen science became somewhat marginalized [7]. In recent decades, however, citizen science seems

to be growing in relevance and number of projects (for review, see [8]). Volunteer-based, conservation-focused projects, such as butterfly monitoring schemes (BMSs) and bird counts, have been popularized since the 1960s and 1970s in order to raise awareness of the importance of biodiversity [2–4]. Lately, the most on-trend citizen science initiatives are the so-called "bioblitzes", which are events where both professionals and local volunteers carry out an intensive survey of the biota of one specific area during a short period of time, usually no longer than three days [4,9–11].

Two main factors have been suggested that contribute to the recent boom of citizen science: (1) the widespread use of the internet, which has facilitated interaction and data flow between professional scientists and amateur scientists, and (2) the development of smartphones, which are used to communicate and share information. These two factors have resulted in the democratization of citizen science as they make science more accessible to most of the population [12–14]. Additionally, citizen science benefits professional scientific research, as it enables the gathering of data at a pace and coverage that would be impossible by isolated efforts due to time and resource limitations [3]. This is especially relevant in research that involves large spatial and geographical scales as well as in urban ecology, where there are parts of the area of study that could not be accessible (i.e., private properties) [3,15]. In relation to this, it should be emphasized that while professional scientists usually focus their sampling efforts on natural areas, amateur scientists tend to do so in urban and rural areas [16]. Thus, amateur science should be viewed as a complement to professional science in many instances. This is of particular significance in the current scenario where some of the traditional natural sciences are declining [17], particularly taxonomy [18].

Many studies have shown evidence that a high percentage of the biological data for various taxonomic groups are provided by citizen science activities. Over 60% of the new animal species that have been described in Europe since the 1950s have been found or rediscovered by nonprofessional taxonomists [19]. Another example highlighting the significance of citizen science is the substantial contribution that it makes to the data available in the Global Biodiversity Information Facility (GBIF, https://www.gbif.org/; accessed on 20 February 2023). A considerable percentage (up to 50% of all occurrence records) of the information in the GBIF is derived from citizen science efforts [20]. GBIF is the main platform for biodiversity data on a planetary scale (as of November 2023, it has over 2.5 billion observations; nearly 440 million for plants). Mainly because it is funded by governments, this platform is regarded as a sort of "official" world biodiversity database, often including all available occurrence data from public research institutions (e.g., herbaria, museums) of all participating countries (see [21] for the example of Spain).

Various citizen science platforms (websites and mobile apps) have been developed in recent years, facilitating the study of biodiversity and the environment by both professional and nonprofessional scientists or volunteers [14]. One of the most widely known is iNaturalist, which is both a web-based and mobile app citizen science platform. In this work, we will describe what iNaturalist is and, most importantly, what its potential uses and limitations in botany are. We conclude by offering suggestions to overcome the limitations identified in plant research and share some lessons learned from our experience using this platform.

2. What iNaturalist Is

iNaturalist (https://www.inaturalist.org/; accessed on 20 November 2023), defining itself as an "online social network of people sharing biodiversity information to help each other learn about nature", was created in 2008 as an end-of-Master's project by Ken-ichi Ueda, Nate Agrin and Jessica Kline at the University of California Berkeley's School of Information. In 2014, the platform became an initiative of the California Academy of Sciences and later, in 2017, a joint initiative with the National Geographic Society. iNaturalist, today a nonprofit organization, is associated with many local and regional organizations (nodes) throughout the world that promote the use of the app, manage

the observations and operate as a network (https://www.inaturalist.org/sites/network; accessed on 22 February 2023). Either the global site or local node sites can be used for uploading or checking fauna and flora records.

This platform's basic functional unit is the observation, which is a record of an encounter with a single organism and is usually associated with a media file (typically a picture, but for some animals, also audio files). Observations can be recorded by documenting a living or dead organism or some other trace of its presence, such as sounds, footprints, excrement or any kind of animal architecture (bird nests, spider webs, etc.). For each observation, iNaturalist allows the following metadata to be added: date, geographic coordinates, geographical precision of the observation, observer identification, taxonomic identification, degree of confidence in the identification, evaluation of the data quality and whether the organism is cultivated/captive or wild. Of all these fields, only the observer, coordinates and date are compulsory to display the observation. The others, while useful, are optional.

Anyone over the age of 13 can be a member of the iNaturalist community, and once they have signed up, they can contribute by uploading observations (acting as an observer), validating others' observations (acting as an identifier) or interacting with other members through public comments or private messages. Apart from the regular members, in iNaturalist there are curators, who are users who voluntarily collaborate by reviewing and updating taxonomic data, among other activities.

As of November 2023, iNaturalist had almost 2.9 million users and 165 million observations of more than 430,000 species, thus making it possibly one of the largest citizen science web portals in the world (the largest is likely eBird with over 1 billion occurrences; https://ebird.org/; accessed on 5 November 2023). Specifically for plants, iNaturalist has almost 67 million observations (of over 154,000 species by nearly 2 million users), which makes this portal probably the largest in the world for this taxonomic group. Other citizen science platforms devoted exclusively to plants or that include plants contain a much lower number of occurrences and/or species; e.g., the global-oriented PlantNet (about 20 million observations of ca. 45,000 species; https://identify.plantnet.org/; accessed on 5 November 2023) or Project Noah (about 200,000 observations; https://www.projectnoah.org/; accessed on 5 November 2023), or the country-specific Plant Photo Bank of China (about 14.5 million observations of 56,000 species; https://ppbc.iplant.cn/; accessed on 5 November 2023). Overall, it could be said that iNaturalist has grown quickly in all its aspects since its creation (Figure 1), at least partly thanks to a number of strengths. Despite this, there are also some aspects that could be improved or that require the responsibility and scrutiny of researchers when using iNaturalist as a data source in plant science, a topic that will be further reviewed in this article.
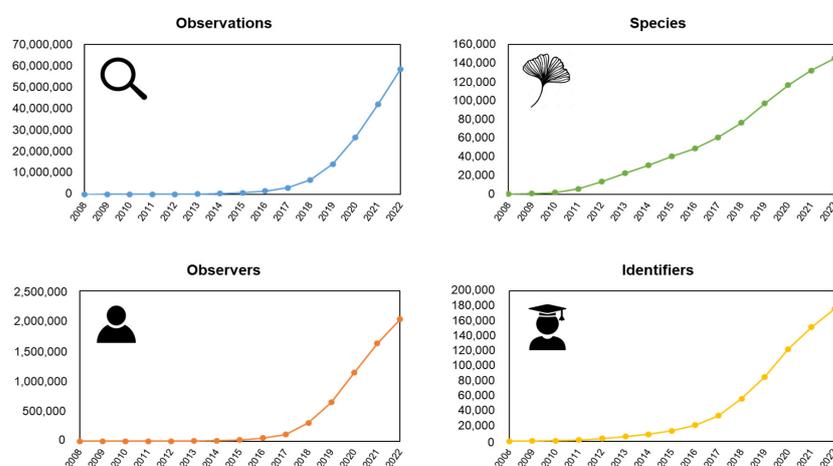

Figure 1. Evolution in the yearly number of observations, species, observers and identifiers in iNaturalist since its creation to the present (2008–2022). Graphs prepared using raw data available on the official iNaturalist website (https://www.inaturalist.org/; accessed on 20 February 2023).

3. Strengths of iNaturalist: Potentials and New Opportunities for Plant Research

3.1. Low Technical Requirements, Usability and Immediacy

One of the main keys to iNaturalist's success is its usability and low technical requirements: it only needs a camera (or a microphone) to document the observation and an internet connection to upload it. Observations take little time to be uploaded (just a few seconds): with the app installed on a smartphone, images are automatically linked with the GPS (Global Positioning System) coordinates and date, and thus the observation is placed in space and time. Even if there is no internet connection (which may happen in remote areas while doing fieldwork), one can record observations, as the app will save the date, time and location (GPS location can be saved if there is satellite coverage, regardless of whether there is internet connection or not), and uploaded later once the connection becomes available again. In addition, users can easily edit or manually set the date and location, enabling the upload of observations taken with alternative devices (e.g., cameras) or captured in the past.

The iNaturalist interface also plays a crucial role in its success. The mobile app version has the basic appearance of a social network. Users and species profiles are initially shown as a grid of observations, and by clicking on individual pictures, the associated metadata can be consulted, including proposed identifications and users' comments. Observations can also be displayed on a map, allowing users to easily draw boundaries to select only the observations made in a specified area.

3.2. Open Access

All observations (including the images) are released under a Creative Commons license BY-NC by default. This means that, if not modified by the observer, iNaturalist users have the right to distribute, remix or adapt them for noncommercial purposes, provided they ensure that attribution is given to the creator (https://creativecommons.org/about/cclicenses/; accessed on 10 February 2023). The BY-NC is the license under which the observations are sent to GBIF (see below) and it is used by many open-access journals. Authors of the observations, however, are allowed to manually change the conditions of license for their photographs (from public domain to all rights reserved, although the last option is discouraged; https://www.inaturalist.org/blog/48165-we-want-you-to-license-your-inaturalist-photos-before-april-15th; accessed on 10 February 2023). However, even in the latter case, pictures and the rest of the data (geographic coordinates, date) can still be viewed, which is not the case on other citizen science platforms, such as PlantNet. In the latter, public georeferenced occurrences are very scarce; for example, for the very common *Trifolium repens* L., only 304 of the 9716 georeferenced observations (i.e., a mere 3%) were public to the users of PlantNet (https://identify.plantnet.org/es/the-plant-list/species/Trifolium%20repens%20L./data; accessed on 5 November 2023).

Certainly, most of the opportunities offered by iNaturalist rely on the availability of geographical coordinates for all observations, although some restrictions might apply. By default, the coordinates of records are visible to every user unless the taxon is threatened and could be negatively affected by location disclosure (e.g., certain orchids). This threat category can be global (e.g., IUCN Red List) or associated with a particular place and can be updated by platform curators. In any case, observations of threatened species are automatically "obscured" or even set as "private". In the first instance, when an observation is obscured, the coordinates are replaced with those of a random point within a broader area (a 0.2×0.2 degree cell; ca. 500 km^2 at the equator), while in the second instance, when an observation is set as private, the record does not show geographic information. In addition, individual observers can also decide to restrict the coordinates of a given species regardless of its conservation status. Although this is not usually recommended (as obscuration reduces the scientific value of observations), it is justified when it may be suspected that a given population is subjected to certain pressures (e.g., to prevent illegal hunting, exploitation for the pet trade or over-collection of threatened species) or because the observation is on private property. While obscuring the geographical coordinates of

observations of threatened species may be well justified, it significantly reduces the utility of the metadata associated with the observations for generating estimates of geographic distributions and ecological requirements [22]. The only way to obtain the geographic information on observations of threatened species is by directly contacting the user who uploaded the observation, which can sometimes be cumbersome and inefficient. Contreras-Díaz et al. [22] suggested that iNaturalist should simplify the way conservation biologists can access obscured data, thus contributing to the conservation of these species.

3.3. Assisted Taxonomic Identification and Quality Check

iNaturalist was meant to be open to anyone with an interest in living organisms, regardless of their background in biological sciences. For instance, in order to assign observations to a taxon, iNaturalist's app contains an artificial-intelligence-aided identification (through computer vision models [23]). The most recent computer vision model implemented in iNaturalist (v2.8, released in October 2023) allows the identification of ca. 80,000 taxa (https://www.inaturalist.org/blog/85796-we-re-now-modeling-over-80-000-taxa-a-conversation-with-alex-shepard; accessed on 15 November 2023). Therefore, even if you are not a professional scientist or an experienced naturalist, the app can help you identify the observed specimen.

One of the fundamental pillars of iNaturalist is the interaction among users, who can be aided by crowdsourced species identification. On this platform, users who suggest an identification for records uploaded by other users are categorized as identifiers: the level of agreement between identifiers for one observation is at the core of the validation system. Based on identification consensus and other data quality assessments, an iNaturalist observation can qualify for any of three categories: (1) "Casual" when it includes a date and it is spatially georeferenced, but lacks a media file supporting the observation or the organism is cultivated or captive; (2) "Verifiable—Needs ID" when, in addition to date and coordinates, it has a picture/sound and is a wild organism but has not reached the "Verifiable—Research Grade"; and (3) "Verifiable—Research Grade" when >2/3 of the identifiers agree with a species rank name. Note that under certain circumstances, an observation identified at the genus level (or another category below the family) may obtain the "Research Grade" (hereafter RG) label if no further identification below this level is possible. This occurs when the community agrees on an identification at that level below the family and votes that the observation does not require further identification. For instance, some observations of the *Sarcoscypha* genus could not be identified at the species level, as microscopic observation of the spores is required to tell the different species apart (e.g., see https://www.inaturalist.org/observations/154666574 and https://www.inaturalist.org/observations/150917462; accessed on 10 May 2023). Other examples include at least 20 observations of lichens belonging to the subfamily Parmelioideae, which, although identified only to the subfamily level, reached RG based on user agreement (e.g., https://www.inaturalist.org/observations?lrank=subfamily&place_id=any&quality_grade=research&taxon_id=48327&verifiable=any; accessed on 14 May 2023).

Crowdsourced species identification is aided by the ability to add comments, which facilitates discussion among amateurs and experts (for example, on specific questions about morphology or systematics or of other natures). Indeed, iNaturalist encourages taxa identifiers to provide a reason for an ID disagreement as a comment. Another resource that iNaturalist offers that may help in the identification process are the "guides" (https://www.inaturalist.org/guides; accessed on 9 March 2023), which are species lists that apply to a given area (e.g., the Cactaceae guide for the Mexican state of Nuevo León; https://www.inaturalist.org/guides/1424; accessed on 9 March 2023) and that can be shared with other users. Another strategy that identifiers can use is to apply the "compare tool", which enables the photograph of the observation to be identified to be compared with other observations of similar species observed nearby. Also, from the iNaturalist platform, it is possible to directly access the description and photographs of the species published on Wikipedia, which may facilitate identification and provide additional information.

3.4. Encouragement of the Interaction between Users and Versatility

In addition to the crowdsourced species identification system, iNaturalist also offers the opportunity to send private messages to other users as another way to encourage interaction among members. There is also a forum (https://forum.inaturalist.org/; accessed on 8 February 2023), which is a place to discuss not only general but also all specific iNaturalist-related topics, including bug reports. Users can also interact with each other by joining "projects", which are multiple records grouped together. There are three types of projects: "collection projects", which display all records that match certain requirements (taxon, date, location, data quality, media type); "traditional projects", which contain observations that have been manually added to the project and are not limited to standard search filters; and "umbrella projects", which are projects that include a set of other already existing projects, usually with characteristics in common.

Projects have been shown to be a versatile tool, as they can be useful, for instance, to run bioblitzes (e.g., *Biodiversity Blitz 2022 Melbourne*; https://www.inaturalist.org/projects/biodiversity-blitz-2022-melbourne; accessed on 20 February 2023; *Biomaratón de Flora Española 2021* and subsequent editions [11]; https://www.inaturalist.org/projects/ii-biomaraton-de-flora-espanola; accessed on 16 May 2023), field campaigns and expeditions (e.g., expedition to the Sucusari River in the Amazonian rainforest in 2022; https://www.inaturalist.org/projects/sucusari-expedition-2022; accessed on 20 February 2023), or even to supply checklists or floras for a defined territory, either at infranational level (e.g., *San Diego County Plant Atlas*; https://www.inaturalist.org/projects/san-diego-county-plant-atlas; accessed on 26 December 2023), national level (e.g., *Flora of Cambodia*; https://www.inaturalist.org/projects/flora-of-cambodia-8722a3eb-1cb3-496f-9d9f-d1569218cbac?tab=about; accessed on 1 December 2023) or supranational level (e.g., *Florapyr Pirineos/Pyrénées*; https://www.inaturalist.org/projects/florapyr-pirineos-pyrenees?tab=about; accessed on 1 December 2023).

Projects, in addition to being used for tracking and displaying a set of observations, have the major advantage that they allow the collection of additional data: a project creator can decide to make it compulsory to fill in some custom fields in the project in order to obtain additional information that would be useful for the study. A wide range of possibilities can be opened by adding extra fields, including monitoring of threatened and invasive species, monitoring of plant pests and diseases, evaluating restoration performance, studying phenology or identifying plant–animal interactions. For example, an iNaturalist project for monitoring invasive alien plants in the Costa Brava of Spain (https://www.inaturalist.org/projects/life-medcliffs-xarxa-de-voluntaris; accessed on 12 March 2023) added specific fields to record some interesting information (e.g., number of individuals, area occupied by them and their life stage, i.e., seedlings, vegetative, reproductive or senescent individuals). A second example is the project for documenting biological control of weeds in New Zealand (https://www.inaturalist.org/projects/biocontrol-of-weeds-in-nz; accessed on 12 March 2023), in which each observation included the life stage of the monitored insect, the host plant species and the type of herbivory. Finally, the role of iNaturalist projects in education cannot be overlooked, as it can be a valuable tool for teaching students about topics such as taxonomy, ecology and biodiversity conservation. Positive experiences in both secondary schools and universities have been reported throughout the world (e.g., [14,24]). The launching of over 700 iNaturalist projects during the period 2014–2021 in a small country like Spain alone [25] can be taken as proof of their usefulness.

4. Potential of iNaturalist for Distributional, Taxonomic, Conservation and Biodiversity Management Studies: Some Relevant Examples

Citizen science can also increase the number of records available, which is particularly valuable for estimating the spatial distribution of plant species. In fact, the iNaturalist platform frequently documents the most recent records of endangered and endemic plant species (Table 1). For instance, the SICAF (*Save the Iberian & Canarian Flora*) project aims to establish a network of observers in Spain to monitor threatened vascular plant

species [26]. As of now, 112 members have joined the project and have successfully gathered 10,500 observations of 470 threatened species, providing crucial information for prioritizing conservation efforts in the region. Gaier and Resasco [27] demonstrated that incorporating iNaturalist records doubled the number of documented occurrences of *Telesonix jamesii* (Torr.) Raf. compared to using herbarium data alone. Furthermore, observations from iNaturalist can also reveal new populations of native or endemic taxa, expanding the known spatial distribution area for specific taxa. For example, a new population of *Tiputinia foetida* P.E. Berry & C.L. Woodw., a myco-heterotrophic plant previously thought to be endemic to northeastern Ecuador, was discovered hundreds of kilometers south in Peru and added to iNaturalist as a record (https://www.inaturalist.org/blog/32964-this-plant-was-found-hundreds-of-kilometers-from-its-known-range-observation-of-the-week-4-12-20; accessed on 15 April 2023). In Argentina, new localities of the endemic Fabaceae *Lupinus aureonitens* Gillies ex Hook. & Arn. have been documented by iNaturalist users, expanding the distribution area of this species [28]. As a last example, one location of a presumed extinct species, *Gasteranthus extinctus* L.E. Skog & L.P. Kvist (Gesneriaceae), was recorded on iNaturalist but remained overlooked (as it was identified only at the generic level) until the species was rediscovered in the field two years later by a team of professional botanists [29]. These examples highlight the importance of citizen science in providing valuable information for improving our understanding of plant species distribution and conservation efforts. Furthermore, observations shared in iNaturalist have even enabled the discovery of new taxa (Table 1). A new species of *Gonolobus* (Apocynaceae) was described thanks to observations uploaded in NaturaLista, the Mexican node of iNaturalist, and the new species, *G. naturalistae* M.G. Chávez, Pío-León & L.O. Alvarado, was named after NaturaLista [30]. Also in Mexico, *Aphyllon chiapense* Franc. Gut. & L.O. Alvarado (Orobanchaceae) has been recently described thanks to the fact that observations posted in iNaturalist did not correspond in terms of morphology or distribution to any of the *Aphyllon* species extant in southeastern Mexico [31]. Also, based on the differential morphology and geographic location of iNaturalist records, a new species of *Thismia* (Thismiaceae) was described for Colombia [32]. In New South Wales, Australia, good-quality photographs of flowering material that were uploaded to iNaturalist enabled the description of a new species of *Lomandra* (Apiaceae), *L. briggsiana* R.L. Barrett & T.C. Wilson [33]. Similarly, on the island of Mindanao (Philippines), a new species, *Cryptocoryne esquerionii* Naive & Wongso (Araceae), was discovered because a citizen scientist documented an unknown species [34]. It can be expected that in the future, the discovery of plant species through iNaturalist will become more frequent as the tool becomes more popular among citizens.

The role of citizen science can also be essential in the monitoring of alien plant species (Table 1). Many alien plant species are primarily distributed in urban ecosystems, where it is more common for citizen scientists to collect observations for iNaturalist. In Texas, the incipient naturalization of *Noccaea perfoliata* (L.) Al-Shehbaz (native to Europe, eastern Asia and northern Africa) has been partially monitored based on several species records in the iNaturalist app [35]. The "BambApp" project employed citizen science to evaluate the invasive potential of bamboo species in northwestern Italy; over 10 months, 871 bamboo populations were recorded on iNaturalist, with *Phyllostachys aurea* (André) Rivière & C. Rivière identified as the most prevalent species. At the same time, the project provided reliable information for regulating bamboo commerce [36]. In Ecuador, using herbarium data and observations uploaded to iNaturalist, the presence of eight different alien taxa of *Kalanchoe* (Crassulaceae) in the wild could be confirmed. Furthermore, through observations of cultivated individuals, it was found that all the taxa recorded in the wild are cultivated in Ecuador, suggesting that the pathway for the establishment of these taxa is the trade in ornamental plants [37]. These examples emphasize that involving the public in the monitoring of alien plant species through citizen science provides valuable insights for the management and regulation of these species.

Table 1. Some examples of the potential of iNaturalist for distributional, taxonomic, conservation and biodiversity management studies in plants.

Taxon	Region/Country	Reference and/or iNaturalist Link
INCREASE IN RECORDS OF NATIVE, ENDEMIC OR THREATENED SPECIES		
Telesonix jamesii (Torr.) Raf. (Saxifragaceae)	Increase in number of records in the United States of America	[27]
Lupinus aureonitens Gillies ex Hook. & Arn. (Fabaceae)	New localities in Argentina	[28]
Tiputinia foetida P.E. Berry & C.L. Woodw. (Thismiaceae)	First record in Peru	https://www.inaturalist.org/observations/40905049; https://www.inaturalist.org/blog/32964-this-plant-was-found-hundreds-of-kilometers-from-its-known-range-observation-of-the-week-4-12-20 (accessed on 15 April 2023)
Eucrosia stricklandii (Baker) Meerow var. *stricklandii* Amaryllidaceae)	New locality in Ecuador	https://www.inaturalist.org/observations/93785060 (accessed on 15 April 2023)
Gasteranthus extinctus L.E. Skog & L.P. Kvist (Gesneriaceae)	Rediscovery of a presumed extinct species in Ecuador	[29]; https://www.inaturalist.org/observations/36478271; https://www.inaturalist.org/observations/36473651; https://www.inaturalist.org/observations/36415279 (accessed on 17 November 2023)
DISCOVERY OF NEW PLANT SPECIES		
Gonolobus naturalistae M.G. Chávez, Pío-León & L.O. Alvarado (Apocynaceae)	New species described for Mexico	[30]; https://www.inaturalist.org/observations/4447993 (accessed on 10 February 2023)
Lomandra briggsiana R.L. Barrett & T.C. Wilson (Asparagaceae)	New species described for Australia	[33]; https://inaturalist.ala.org.au/observations/59760073 (accessed on 17 November 2023)
Thismia paradisiaca S. Guzm.-Guzm. (Thismiaceae)	New species described for Colombia	[32]; https://www.inaturalist.org/observations/10252116; https://www.inaturalist.org/observations/81910064 (accessed on 17 November 2023)
Aphyllon chiapense Franc. Gut. & L.O. Alvarado (Orobanchaceae)	New species described for Mexico	[31]; https://www.naturalista.mx/observations/10776255; https://www.naturalista.mx/observations/145552685; https://www.naturalista.mx/observations/146226689 (accessed on 17 November 2023)
NEW RECORDS AND MONITORING OF ALIEN PLANTS		
Actinidia chinensis Planch. var. *deliciosa* (A. Chev.) A. Chev. (Actinidiaceae), *Astrantia major* L. (Apiaceae), *Berberis congestiflora* Gay (Berberidaceae), *Eryngium planum* L. (Apiaceae) and *Epilobium hirsutum* L. (Onagraceae)	First records for New Zealand	[38]
Noccaea perfoliata (L.) Al-Shehbaz (Brassicaceae)	First record (and further ones) for Texas (United States of America)	[35]
33 invasive or potentially invasive plant taxa	Detection and monitoring (over a period of 3 years) of populations in Costa Brava (NE Spain)	https://www.inaturalist.org/projects/life-medcliffs-xarxa-de-voluntaris (accessed on 17 November 2023)

Table 1. *Cont.*

Taxon	Region/Country	Reference and/or iNaturalist Link
Kalanchoe (16 species, Crassulaceae)	New records, delimiting ranges and monitoring of taxa expansion in Ecuador	[37]
Phyllostachys aurea (André) Rivière & C. Rivière (Poaceae) and other bamboo species	New records, delimiting ranges and characterizing populations in NW Italy	[36]
Asparagus falcatus L.	First record for Spain	https://www.inaturalist.org/observations/109741140 (accessed on 17 November 2023)

5. Using iNaturalist in Plant Research: Key Considerations and Recommendations

While iNaturalist offers enormous potential in plant research, it is important to consider that during the citizen science process, certain drivers can lead to observations of questionable quality and therefore affect the validity of the scientific results. Low-quality observations (e.g., due to unrepresentative photographs or failure to indicate that a taxon is cultivated) and identification errors (e.g., due to a lack of expertise among identifiers) can lead to an observation reaching the RG level without being properly validated. A researcher might assume that an observation that has reached the RG level and has been included in GBIF is reliable for research purposes. However, solely selecting observations labeled as RG in iNaturalist may be insufficient to obtain reliable data, as potential errors can accumulate during observation and identification. While we recognize that the decision to use or discard a record obtained through iNaturalist ultimately rests with the researcher, in this section we describe six drivers of low-quality observations throughout the iNaturalist citizen science process. In order to promote the use of the most reliable data possible from iNaturalist, we provide some suggestions for observers and identifiers as well as for the iNaturalist platform. Additionally, we discuss some considerations that researchers should take into account to avoid using unreliable data. Finally, we provide some insights on recurrent bad practices by users in bioblitzes based on our experience in organizing three editions of *Biomaratón de flora Española*.

5.1. Low-Quality Photographs Associated with the Observations

Observations based on low-quality photographs may not be reliable for use in research purposes. Therefore, we suggest that these observations should not be classified as RG but rather as "Casual". As active users of iNaturalist, we have observed that the quality (resolution, framing and/or representativeness) of the images included in the records is sometimes not enough to identify the taxa. Quality deficiencies include images that are overly focused on a specific detail of a part of the plant (e.g., only a leaf has been photographed) and images where the plant is too far away (see Figure 2A for example). In all cases, but particularly for taxa that are difficult to identify, it could be beneficial to include a set of multiple images. Each image should capture different details of the specimen, such as leaves, flowers, fruits and any other characteristic (hairs, spines, etc.) that would aid accurate determination of the taxon (Figure 3) in order to be labeled as RG. In addition to a set of multiple images, the inclusion of a size reference (a ruler, a coin, etc.) or a standard color chart (Pantone or similar) could also provide other taxonomically valuable characteristics (such as color or size), thus facilitating the correct taxon assignment to the specimen or specimens shown in a record (see Figure 3).
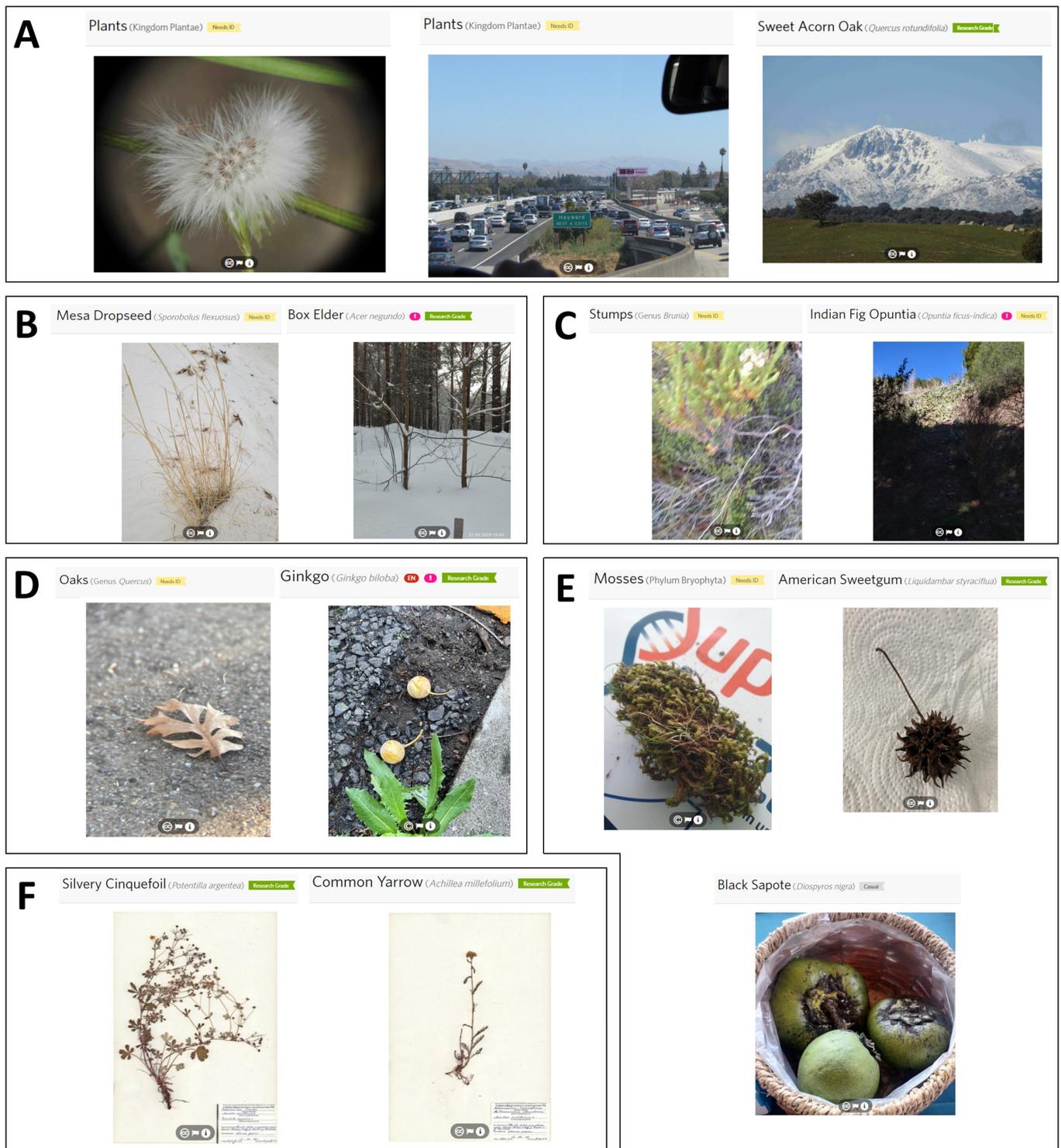
Figure 2. Some examples of low-quality photographs associated with observations. (**A**): records including images that are too detailed (left) or taken from too far away (center and right), potentially leading to a wrong assignment of the taxa. (**B**): records including a withered plant (left) and leafless trees (right). (**C**): records including a blurred image (left) and an image with too much contrast (right). (**D**): records including only a leaf (left) and a fruit (right) outside the habitat of the taxa to which it belongs. (**E**): records including harvested plants or parts of plants. (**F**): records including specimens from herbaria. All records are extracted from https://www.inaturalist.org/ (accessed on 1 February–1 December 2023). Observer identification is deliberately omitted.
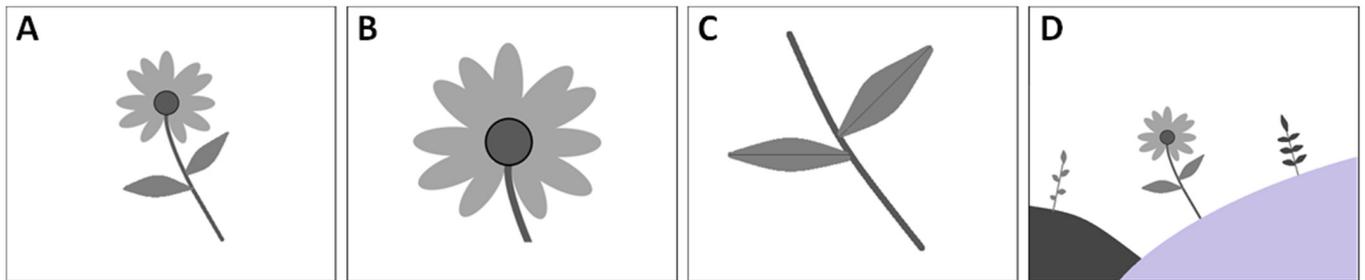
Figure 3. Guidelines (and examples) of what should be included in every set of images. (**A**): an image of the whole plant; (**B**,**C**): detailed images of some organs of the plant; (**D**): an image of the plant in the habitat where it was found. The first example (*Borago officinalis* L.; https://www.inaturalist.org/observations/151200948; accessed on 23 April 2023) follows the scheme presented here. The second example (*Agave fourcroydes* Lem.; https://www.inaturalist.org/observations/151282975; accessed on 23 April 2023) contains more photographs, as the observer added some of the taxonomically important characters in the genus *Agave*, such as the terminal spine, the lateral teeth and the panicle.

Furthermore, we would like to emphasize that it is not recommended that RG be assigned to observations based on photographs of withered plants or leafless trees (Figure 2B). This practice significantly complicates the determination process and raises the probability of identification errors. Ideally, all the photographs should have sufficient resolution, not be blurred or have blurred parts, not be unfocused, not be overexposed, and not have too

much contrast (i.e., no strong differences between light and dark areas) (Figure 2C). Such a set of several (at least 4–5) high-resolution images has already been proposed as a standard for photographs intended to complement herbarium specimens (i.e., as "fusion vouchers") or for making "photo vouchers" [39]. We believe that this standard could easily be applied to iNaturalist, not as a compulsory requirement, but rather as a "strong recommendation" if the observer wants their uploaded observation to reach RG status.

Additionally, observations based on photographs of seeds, fruits or leaves found on the ground (Figure 2D) as well as those of uprooted plants or harvested fruits (Figure 2E) may be problematic. These observations might be based on photographs taken outside the natural habitat of the species, located hundreds of meters or even kilometers away from the mother plant and, as a result, the geographic coordinates associated with these observations would not be reliable. However, detecting propagules of species might be highly valuable for identifying processes such as long-distance dispersal, and these observations could be retained in the application with the status of "Casual" instead of RG.

We also recommend that dried herbarium specimens (Figure 2F) should not be included as valid observations, as iNaturalist was neither originally conceived nor designed to be a platform to host digitized collections nor to digitize extant collections; there are virtual herbaria or platforms specifically designed for such a function (e.g., Symbiota; https://symbiota.org/; accessed on 10 May 2023). Rather, iNaturalist observations can be a good complement to herbarium vouchers (e.g., [40]).

5.2. Errors of Taxonomic Identification

Low-quality photographs increase the risk of identification errors, invalidating the use of the respective observation for scientific research. However, other sources of errors may also hamper taxonomic identification. The most recurrent is the lack of expertise among observers, and also in most cases, the lack of expertise among identifiers. Unfortunately, the presence of misidentified records is widespread throughout iNaturalist. For example, in groups of intricate taxonomy, it is not uncommon that the picture representing the taxon is not the intended species or that it does not display key features. For taxonomically challenging groups, the percentage of misidentified observations can be high; for example, for lichen species that may be identified through macromorphological traits, only 59% of the observations were identified correctly [41]. The problem is aggravated when it involves observations labeled as RG (Figure 4), as these identification errors may spread significantly and reach a much wider audience by their being fed to the GBIF. Therefore, for these difficult groups, we recommend opting for the GBIF tab that allows the exclusion of data in the downloaded GBIF dataset.

We believe that by focusing on improving the system of record validation and assignment of the RG label, there is room to make the verification process more efficient, minimizing the number of misidentified records before making them available for scientific use. The easiest and most straightforward way to proceed would be by requesting a higher number of identifiers agreeing on the same identification before categorizing records as RG. An alternative to increasing the number of identifiers would be to require expert validation, although this may be problematic and even discouraging for many users. It is tempting to propose, for instance, mandatory validation by an expert in the taxonomic group as a prerequisite for submitting an RG observation to GBIF, these experts being a sort of "premium user" (e.g., botanists or amateurs but with proven experience in certain taxonomic groups whose vote would have more value than that of others). This latter option (a casting vote or a "super vote"), although seemingly appropriate to address this issue, could be discouraging for some users such as newcomers who could feel inferior or think that their contribution is not worth much. In addition, deciding who has enough expertise for a given group of plants would not be straightforward, either. The lively discussion on whether experts should be empowered over nonexperts in identification tasks (e.g., https://forum.inaturalist.org/t/why-not-empower-recognised-experts/14 419; https://forum.inaturalist.org/t/implement-an-ispot-style-reputation-system/6998;

https://forum.inaturalist.org/t/search-users-profiles-to-find-experts/16958; accessed on 9 March 2023) could be interpreted as an indication that the validation process for iNaturalist observations should be strengthened. In this regard, finding a balance between inclusivity and accuracy is key to enhancing the platform's effectiveness.
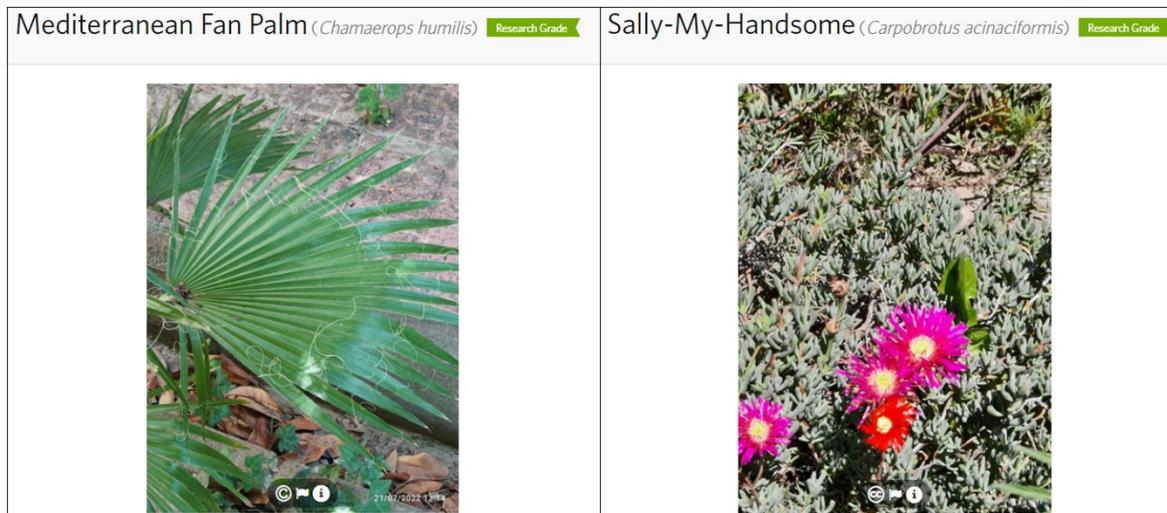

Figure 4. Records including misidentified specimens with the "Research Grade" label. The left observation is *Washingtonia filifera* (T. Moore & Mast.) H. Wendl. ex de Bary and not *Chamaerops humilis* L. The right observation is *Malephora crocea* (Jacq.) Schwantes instead of *Carpobrotus acinaciformis* (L.) L. Bolus. Both records are extracted from https://www.inaturalist.org/ (accessed on May 2023). Observer identification is deliberately omitted.

5.3. Lack of Distinction between Captive and Wild Species Observations

In order to obtain ecological data or to know whether a specimen (or a population) is cultivated or occurs in the wild, it could be beneficial to include images not only of the whole plant but also of the plant within the habitat where it has been found. Unfortunately, it is a common practice not to include photographs of the habitat where the plant is growing, which impedes, in most cases, knowing whether the plant is cultivated or wild. In addition, the "cultivated" tag is routinely not marked by iNaturalist users, even in cases of clearly cultivated plants (Figure 5). This issue is particularly problematic for research carried out with plants that are widely cultivated (e.g., Aizoaceae, Cactaceae or Crassulaceae).

If an observation of a captive species is uploaded without the captive tag being marked, it may mistakenly be categorized as RG, resulting in its upload to GBIF (e.g., Figure 5). The inclusion of allegedly wild occurrences that are actually cultivated may result in large biases in research, particularly in biogeographical and ecological studies. For instance, if records of cultivated individuals are included when developing an ecological niche model (ENM), this model would not be able to correctly predict the potential distribution of the species. It should be kept in mind that cultivated individuals could occur in ecological conditions that are outside the realized niche of native populations because of watering, fertilization or protection from freezing [42,43]. Although it is possible to download only the biological data that has a voucher from GBIF, excluding the records from iNaturalist would result in the loss of valuable and useful data. Therefore, scientists working with data from this science platform should make an additional effort to state when using the image whether an observation is wild or cultivated (which is not always straightforward; e.g., as in the example of Figure 5A). As mentioned above, the "cultivated" tag is not marked in most observations, which means that it cannot be used as a filter. Therefore, before achieving the RG label, an important recommendation for the iNaturalist platform would be to make the marking of species as captive or wild as a mandatory step, as this would ensure greater accuracy and reliability in species observations to be used for research purposes.
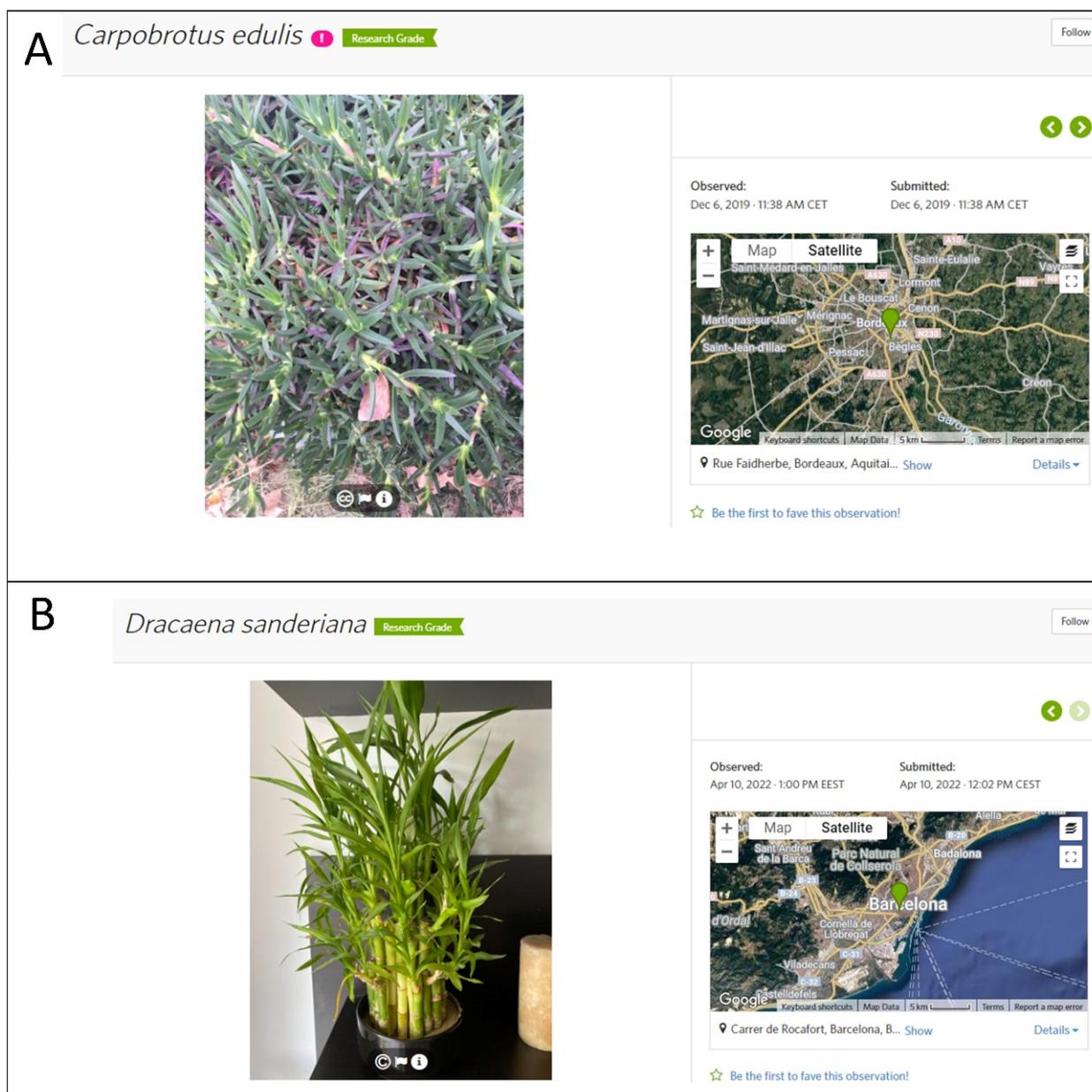
Figure 5. Records including images of planted individuals lacking the "cultivated" tag. (**A**): although there is no trace of cultivation judging from the picture, the plant shown is a South African Aizoaceae that is obviously not capable of growing naturally in inland France. (**B**): observation that contains a picture of a *Dracaena sanderiana* Mast., a tropical plant that has been widely cultivated, recorded in Barcelona, where the climate conditions do not allow this species to survive naturally. These records have been extracted from https://www.inaturalist.org/ (accessed on 1 May–1 December 2023). Observer identification is deliberately omitted.

Emphasizing the need to distinguish whether an observation is wild or cultivated does not mean that observations including cultivated specimens have no value. Recording cultivated specimens in iNaturalist is still useful for various reasons; for example, cultivation can be a previous stage in invasions [44]. Moreover, we would also like to note that labeling cultivated plants as "Casual" is sometimes problematic, as in biology, this term is widely used to designate alien plants that have escaped from cultivation or that occur outside cultivation but are still not fully established [45]. We propose that instead of using the term "Casual" for cultivated species, alternative tags such as "not wild" be employed.

5.4. Lack of Accuracy in the Geographic Coordinates

Lack of accuracy in the location of a given record can hinder its use for research. Leaving aside the possibility of obscuring coordinates (which is a very recommendable option for some cases; see above and below), there are quite a few cases of too-low accuracy among iNaturalist observations, even of dozens of km (Figure 6A). This may happen because the observer added the accuracy manually—probably because the photographs were taken with a camera lacking a built-in GPS or their cell phone's GPS is disabled—and they are not able to remember exactly where the observation was made. It is even more common that the accuracy field is blank, as this information is not required when uploading an observation. Unless it is registered by means of the iNaturalist app in situ (which assigns the accuracy automatically), the observer has to provide the accuracy in all other cases (even when the location is assigned using the metadata from a photo). As including observations with too-low accuracy (or lacking it) can be problematic for many studies (especially those that rely on species distribution data such as ENM), we recommend making geographic accuracy a requirement for an observation to reach the RG level, or at least a strong recommendation; an automatic alert warning that this information is lacking would be useful in this regard.
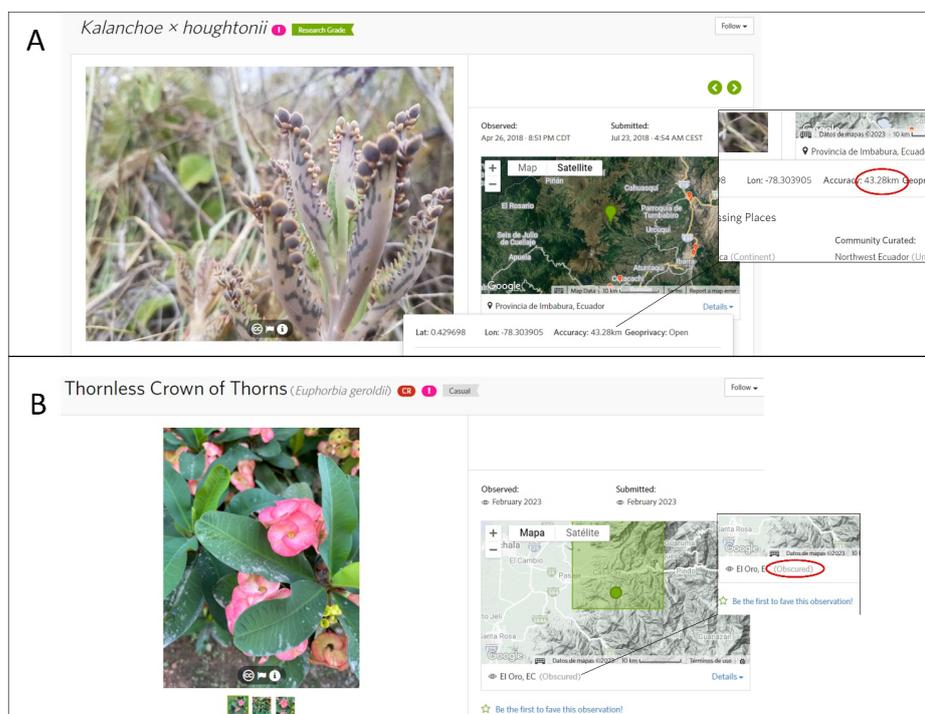

Figure 6. Examples of records on iNaturalist without precise geographic information. (**A**): A record with too-low geographical accuracy. (**B**): Example of a threatened species in its native range that has been introduced in another region where it has obscured coordinates due to its threatened status. Both records are extracted from https://www.inaturalist.org/ (accessed on 1 May–15 November 2023). Observer identification is deliberately omitted.

Geographic coordinates of taxa that are included in the global IUCN Red List of threatened species are automatically obscured (https://forum.inaturalist.org/t/updating-iucn-red-list-conservation-statuses/25712; accessed on 22 February 2023). Obscuring coordinates of endangered species could, however, be a problem in one particular case: when a threatened species has been introduced in non-native ranges, where it could even become invasive (this last is known as the "conservation paradox of threatened and invasive species"; see [46]). When this happens, the coordinates of all records of these species will be obscured irrespective of whether they correspond to native or introduced instances (as shown in Figure 6B). Even when the species is flagged as "introduced" for a

given country or region (with an exclamation mark), all its records could be still obscured (Figure 6B), which limits the possibility of monitoring these species within their introduced range through iNaturalist. In these cases, it would be desirable for iNaturalist to allow geographical coordinates to be shown, especially if the record concerns a species behaving as a true invasive in the new area. This improvement could lead to a better understanding of the mechanisms of biological invasions.

5.5. Duplicated Records

Though they are not common, there are cases of true duplicate records in iNaturalist; i.e., different records referring to the same individual at the same moment by the same observer (Figure 7). Duplicates should be avoided as they are adding noise, which would mean additional work of cleaning when data are used for research. In contrast, observations of the same individual by different people, or even of the same individual by the same observer but on different dates, should not be simply regarded as duplicates, as they can indeed offer useful information (e.g., phenology), and most projects focused on demographic or conservation monitoring would find repeated observations useful. In some cases (e.g., ENM), "pseudo-duplicates" would actually add noise and researchers may need to discard them. A simple technical improvement would be setting an automatic alert in the cases where an observation is in the same place (or separated by just a few meters to account for possible GPS errors) as an existing observation of the same taxon. This would alert the observer to possible duplications and they could refrain from registering it (or go ahead, e.g., in demographic monitoring). Based on our experience, the badge-like appearance of the iNaturalist interface for projects (Figure 8) might favor the accumulation of pseudo-duplicates and even true duplicates in iNaturalist. Some people could see a bioblitz event more as a competition than as a tool to improve biodiversity knowledge of a given place (competition could be one of the main reasons to participate in a bioblitz [47]). A way forward could be to give more weight to the quality of the observations instead of quantity. Rewarding high-quality observations in bioblitzes or similar projects could mitigate the accumulation of pseudo-duplicates and true duplicates in iNaturalist; for instance, badges would be earned by recording high-quality observations (e.g., having a set of good photographs depicting the observed plant, ensuring that the geographic coordinates are accurate or making sure that all the optional fields—if present—are filled). This policy, in addition to reducing the rate of duplicates, would also restrain users (or at least some users) from recording in a hurry (which often translates into, for example, blurred or unrepresentative photographs; see also above).

5.6. Taxa Not Accommodable to iNaturalist Plant Taxonomic Reference

iNaturalist uses a single taxonomic reference, which can be viewed as both a strength and a weakness for researchers. Plants of the World Online (POWO; https://powo.science.kew.org/; accessed on 6 February 2023) has been the iNaturalist plant taxonomic reference since the late 2010s. Although POWO (which is curated by Royal Botanic Gardens, Kew) is probably the most comprehensive and authoritative list of the world's plants, iNaturalist users can encounter some problems when either recording an observation or checking its identity, which could potentially discourage some users from recording a given observation. A recently described species or a recent taxonomic change may not have been implemented yet in the reference taxonomy (POWO). For example, both molecular and morphological data accumulated during the last decade [26,48–51] clearly suggest that the palm genus *Washingtonia* is composed of a single species instead of the two-species taxonomy of POWO (https://powo.science.kew.org/taxon/urn:lsid:ipni.org:names:331308-2; accessed on 7 February 2023).
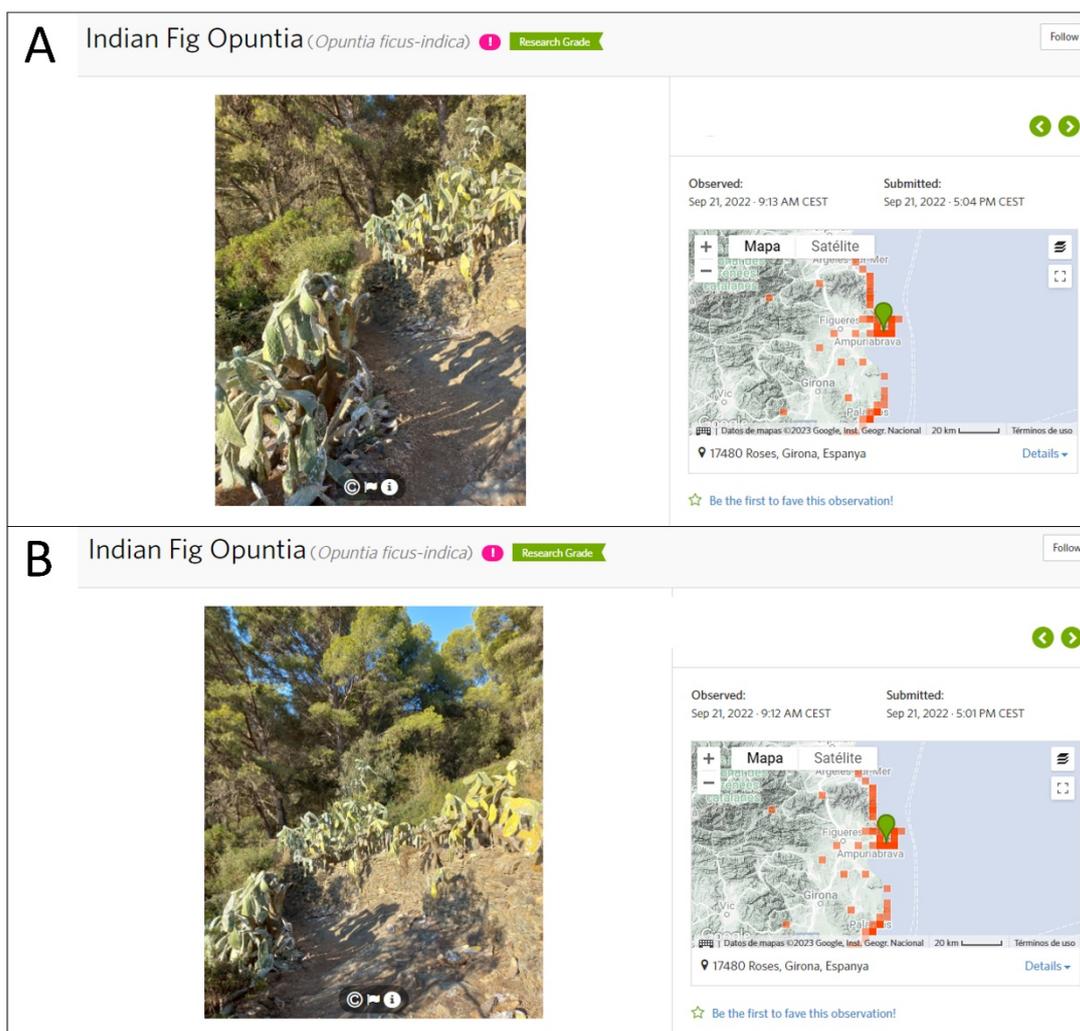
Figure 7. True duplicate records of the same observation. These two independent observations of iNaturalist (**A**,**B**) are based on the same group of individuals and recorded by the same observer just three minutes apart. These two observations are obviously duplicates, extracted from https: //www.inaturalist.org/ (accessed on 10 February 2023). Observer identification is deliberately omitted.

Nevertheless, iNaturalist offers some ways to deal with these discrepancies. For the cases in which iNaturalist does not recognize the name that has been entered, a flag for curation to the higher-level taxon (usually the genus) can be added, accompanied by an explanation about the taxon the user would like to add (and the source or the literature supporting this). When observers disagree with an existing name in iNaturalist (e.g., possible cases of taxa merging, splitting or swapping), they should flag the taxon directly. All cases are evaluated by iNaturalist curators, who may end up creating an alternative list to the POWO reference list. It may happen, however, that while some taxonomic updates in iNaturalist are delayed, in other cases the proposed changes are not accepted. Given this, people using iNaturalist for plant research (e.g., when gathering occurrences for ENM or for searching sampling locations) should be aware of these limitations and keep them in mind when searching for a given species; e.g., when doing a duplicate search for *Washingtonia filifera* (a search under "*W. filifera*" and another under "*W. robusta*") or, in the case of recently described species, doing a search for possible species names that may have included them. There is a current discussion at the iNaturalist forum on how to make some changes in iNaturalist to ease some of these problems (https://forum.inaturalist.org/t/improving-inaturalists-nomenclature-taxonomy/36143; accessed on 7 February 2023).
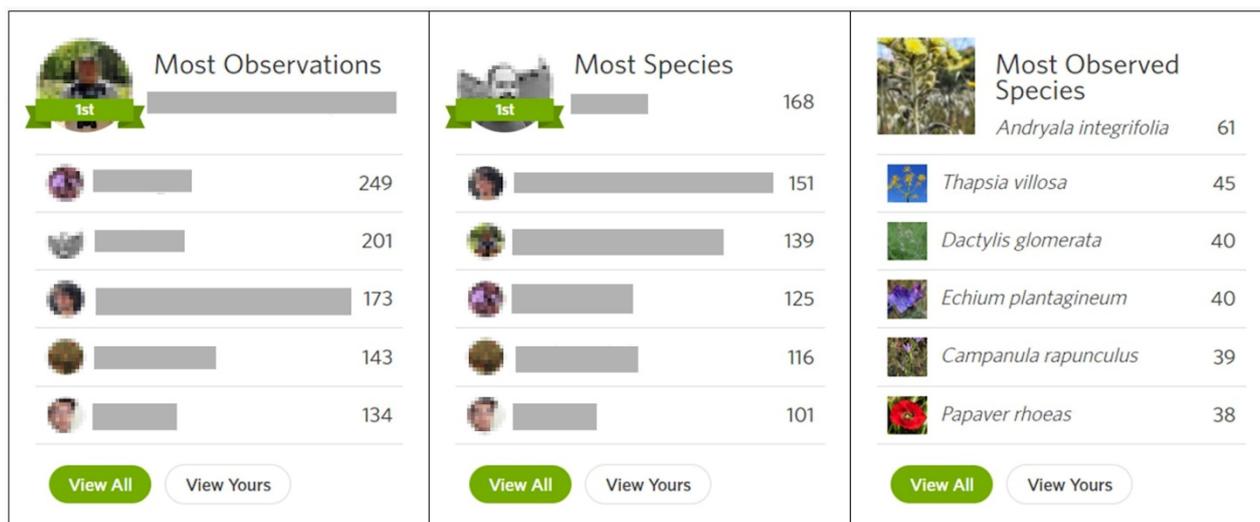
Figure 8. Badge-like appearance of a bioblitz event counter. Image extracted from https://www.inaturalist.org/ (accessed on 12 February 2023), with users' profile pictures blurred for privacy.

6. Recurrent Bad Practice by Users in Bioblitzes: The Experience of the Spanish *Biomaratón*

As explained above, bioblitzes are citizen participation events that often use iNaturalist as the preferred platform. In a bioblitz, citizens photograph plants and animals and upload their observations, but sometimes the objectives of these events are misunderstood as being a competition. Indeed, the Spanish term that is often used for bioblitz, *biomaratón* ("biomarathon"), may suggest this erroneous idea to users. Thus, certain users encourage unhealthy competitiveness, with the intention of making a display of strength on the platform for personal satisfaction, by accumulating either observations or confirmations.

During the first and the second editions of the *Biomaratón de Flora Española* (Spanish Flora Bioblitz), the organizers identified some of these practices as recurrent and discussed them in the Do's and Don'ts of a Best Practices Guide for the third edition of the *Biomaratón* (https://www.inaturalist.org/projects/iii-biomaraton-de-flora-espanola/journal/76268-buenas-practicas-para-participar-en-el-biomaraton-de-flora-espanola-v-1-0; accessed on 20 November 2023), which took place in May 2023. For example, certain users uploaded landscape photos (Figure 2A) several times as different observations. They then identified a different species in each of the pictures, regardless of whether the identity of the species was clear or not or if it even appeared at all in the picture. As explained, these pictures do not provide evidence enough for species identification and so may end up providing inexact information if uploaded to GBIF. Other users performed massive uploads of archive images that were presented as if taken during the bioblitz. While some of these pictures had enough quality to allow species identification, the reader will agree that this information entirely falsifies the period in which a plant appears, as well as its phenologic state. Also, by indiscriminately accepting all identifications by other users, some participants accumulated a high number of confirmations just to push their profile up in the Bioblitz activity ranking. Unfortunately, this attitude leads to many incorrect taxonomic identifications reaching RG status in iNaturalist, which will later appear in GBIF.

To ensure the usability of observations categorized as RG in research, we recommend that the iNaturalist platform implement a reporting and declassification system to identify false or unreliable observations. Furthermore, we suggest that any observation of this kind that receives a designated number of reports by users should not be classified as RG. Instead, these observations should, at the very least, have a warning label attached. On the user side, users of iNaturalist data may want to apply strong filtering to allow only reliable occurrences, which may imply taking only data confirmed by certain users or banning data from unreliable profiles.

7. Conclusions

iNaturalist has become one of the most popular citizen science web portals in the world because of a number of strengths. These strengths, which have been summarized here, include not only its ease of use and low technical requirements, but also its artificial-intelligence-aided and crowdsourced identification. It is also a very versatile platform, as it allows projects to be created that are tailored to certain species or regions and that have been proven to be very useful for educational purposes, for raising awareness of the importance of biodiversity and for empowering communities with knowledge and conservation of nature. Specifically for plant research, iNaturalist is often a very valuable source of data as well as providing a means for carrying out certain types of studies (e.g., demographic monitoring).

Having acknowledged the value of this platform for plant research, we point out that iNaturalist also has some features that, if not considered (and addressed when necessary), may compromise the quality of the observations when they are used for plant research and may therefore compromise the validity of the scientific results based on them. Hence, we believe it is the responsibility of researchers to consider the following issues before utilizing specific data from iNaturalist. One of the most challenging issues is the poor quality of images (in terms of resolution, framing and/or representativeness) included in the observations, which often impedes correct identification of species. One should consider whether observations that have low-quality photographs should not reach RG status. To this end, we propose some guidelines that can result in a set of high-quality photographs that may improve the rate of correct identifications (by including images of taxonomically relevant characters) and to clearly identify whether the observed plants are wild or cultivated (by depicting the habitat). The frequent identification errors can be also linked to the lack of expertise of both observers and identifiers and this issue should be addressed by reinforcing the validation system for observations (e.g., by increasing the minimum number of identifiers agreeing on taxa identification that are necessary for an observation to achieve RG). We also propose some ways to overcome other identified features that can lessen the value of using iNaturalist records in plant research, such as the occurrence of duplicate reports and lack of information on the accuracy of geographic coordinates. Implementing these recommendations would give more weight to the quality instead of the quantity of the observations, which would enhance the utility and reliability of iNaturalist records, ensuring its continued effectiveness as a valuable resource for plant research and conservation efforts.

Strengthening the use of a tool such as iNaturalist in plant research is a very desirable objective in light of the current extinction crisis but also of the recently coined "silent extinction" of botanists [17] and in particular taxonomists [18]. As explained above, iNaturalist can serve as a highly valuable tool in studies and activities with either taxonomic or conservation purposes (e.g., discovery of new species, recording new populations, monitoring of threatened and/or alien species). iNaturalist has even enabled the rediscovery of species that were thought to be extinct, either globally or locally [29,52], so the conservation role of this citizen science tool can be even more impactful in the current scenario of species going extinct before they can be described [53,54]. The current erosion of academic botany (decline in herbaria and their associated staff as well as botany students and university departments) will surely exacerbate this catastrophe, as there will be virtually no one capable of identifying extant taxa or describing new ones. As an illustrative example, the Department of Botany of the Faculty of Pharmacy at Barcelona University, one of the largest of its kind in Spain in the 1990s, has lost over three quarters of its scientific staff since then. Certainly, iNaturalist activities cannot be viewed as a true alternative or solution to the loss of professional botanists, as this tool was not created as an online resource for academic researchers. However, if used with caution (i.e., the researchers taking responsibility for deciding which data are useful and which should be discarded), iNaturalist may help to attenuate and delay the negative impacts associated with the decline in botany.

Also, from a conservation point of view, iNaturalist could avoid, at least in some cases, the need for collecting plant material for vouchering purposes (e.g., [55]), being a good complement if records are directly connected to photo vouchers that are deposited in herbaria ([39]). Finally, it is also worth noting that iNaturalist may help to fill the gap in the large proportion of still unphotographed extant species (e.g., nearly one fifth of the Australian native flora [56]).

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