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A simplified method to detect and monitor alien plant species with invasive potential through citizen science: an application from the European Union–funded LIFE medCLIFFS project volunteers' data

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Abstract

Citizen science is becoming very useful in surveying and monitoring biodiversity. Within the European Union LIFE medCLIFFS project, a network of volunteers has been established for the detection and long-term monitoring of invasive plant species that threaten the endemic flora of Mediterranean cliffs in northeastern Spain. Through iNaturalist, volunteers record various data along a series of 1-km transects. Based on the ca. 700 observations collected by volunteers in 2023 (the first year of the project), a simple and visually attractive methodology for assessing the recorded populations has been developed. This method classifies populations into one of three population dynamics categories: (1) propagative behavior (i.e., populations with seedlings or young plants but lacking senescent or dead individuals); (2) senescent behavior (i.e., showing senescent/dead plants but lacking seedlings/juveniles); and (3) a mixed behavior (i.e., containing both). This methodology, whose outputs are easily interpretable as heat maps, allows the collection of large datasets on invasive plants by citizen scientists, with two main purposes: (1) knowing which species are most concerning based on simple, straightforward observations of their population dynamics; and (2) identifying which regions of the study area are more problematic and where management efforts should therefore be directed.

Introduction

Citizen science (or community science) refers to the involvement of nonprofessional individuals in research and data-collection activities to support various types of studies (Dickinson et al. 2010; Kobori et al. 2016; Pescott et al. 2015). Due to its way of operating, citizen science has been used to collect reliable data and information for the scientific community, as well as for decision makers and the general public (Miller-Rushing et al. 2012; Silvertown 2009), which improves scientific literacy and contributes to society's science education (Bonney et al. 2009; Wals et al. 2014). Nowadays, citizen science is a commonly employed method in research efforts aimed at conserving biodiversity (Dickinson et al. 2010). Numerous state, regional, and local governments, research institutions, museums, nongovernmental organizations (NGOs), and conservation organizations use datasets generated by volunteers to inform their resource management and conservation plans (McKinley et al. 2015). This has resulted in the development of different tools (e.g., mobile applications such as iNaturalist, PlantNet, or Fungipedia) for recording biodiversity and its features across spatial and temporal scales, including phenology, distribution, population size, survival rates, or reproductive success, among others (Dickinson et al. 2010).

The LIFE medCLIFFS project (http://lifemedcliffs.org), co-funded by the European Union's LIFE program (project no. LIFE20 NAT/ES/001223), exemplifies an initiative that uses citizen science, particularly these kinds of tools. This nature conservation project operates in the Mediterranean region of Catalonia (northeastern Spain), specifically along the Costa Brava coastline (with special emphasis in the Cap de Creus Natural Park), which is a cliff-dominated area (hence the acronym "medCLIFFS" for "Mediterranean cliffs") highly impacted by invasive (or potentially invasive) plant species (hereafter IAPS). The main project's purpose is to improve the management of IAPS that threaten the conservation of plant diversity of the Habitat of Community Interest of vegetated Mediterranean sea cliffs with endemic *Limonium* species

Management Implications

The monitoring of invasive (or potentially invasive) alien plant species (hereafter IAPS) based on citizen science along the Costa Brava (within a European Union–funded project) is intended to enhance their management, improving the conservation of Mediterranean sea cliffs with endemic *Limonium* spp. This methodology facilitates the early detection of IAPS populations to be monitored, as recommended by the Early Detection and Rapid Response (EDRR) conceptual framework. By coordinating citizen science networks that collect a large volume of information, this approach facilitates the assessment of IAPS populations at a lower temporal and economic cost compared with monitoring conducted solely by professional experts. Additionally, the generation of this kind of dataset allows redirecting management efforts toward specific species and regions, improving efficiency, for example, by focusing efforts on species that show a high expansive behavior or regions with a disproportionately high concentration of IAPS. Finally, the information obtained could also be used for other purposes, such as feeding spatial risk evaluation systems.

In addition, participatory work through citizen networks contributes to raising awareness about the issue of IAPS, thereby improving understanding of the impacts of invasions on ecosystem services, native flora, and the landscape. Furthermore, a society with a high level of awareness will contribute to the prevention of the introduction of IAPS of ornamental origin and facilitate the social approval of policies targeting invasive species.

(HCI 1240). According to the European Environmental Agency, the conservation status of this habitat in the whole EU is considered as poor (EEA 2024), meaning that, while there is no immediate danger of disappearance, changes in management and policy are required to return the habitat to a favorable status. The project's objectives encompass strategies aimed at preventing and controlling IAPS, which require following an early detection and rapid response (EDRR) conceptual framework (Reaser et al. 2020), as well as efforts to raise public awareness, both of which are equally essential. The collaboration involves the participation of public agencies, scientists, citizen volunteers, an NGO (Flora Catalana), and the ornamental plant sector as partners.

In partnership with Flora Catalana, two participatory networks were established: (1) the LIFE medCLIFFS Observers' Network (LmON) (iNaturalist 2023a), which allows the public to collect observations on up to 184 alien plant species in the Costa Brava area via an iNaturalist app project; and (2) the LIFE medCLIFFS Volunteers' Network (LmVN) (iNaturalist 2023b), which consists of committed volunteers who annually survey transects in the Costa Brava region to identify and monitor the populations of 33 plant species that have been regarded as invasive or potentially invasive in the area. Observations and certain specific traits are recorded in a specifically tailored iNaturalist project that is regularly monitored by professionals. These data are crucial to ensure EDRR, to monitor new invasions and possible reinvasions, and to guide future interventions. Furthermore, the information will help in assessing the invasion risk posed by these species in the Costa Brava, which is of paramount importance, as the geographic area covered by the LIFE medCLIFFS project contains several species of significant conservation concern: *Seseli farrenyi* Molero & J. Pujadas, and two sea lavender species [*Limonium geronense* Erben, and *Limonium tremolsii* (Rouy) P. Fourn.]. These three species have a restricted distribution (as they are strictly endemic to the Costa Brava) and a small population size (the first having fewer than 1,000 individuals) and are highly threatened by alien species, among other factors.

In response to the urgency of this issue, this work focuses on developing a simple methodology to detect species and regions of high risk using citizen science data. To demonstrate this, we used the first year of data collected by the LmVN to illustrate the method's application. Specifically, this methodology allows us to address the following questions: (1) Which IAPS are the most abundant in the Costa Brava, and where are these species mostly concentrated? (2) Which are the most concerning species in terms of population dynamics (e.g., those species exhibiting active recruitment)? (3) Are there differences in the species population dynamics across the Costa Brava?

Materials and Methods

Volunteer Supplementary Formation and Materials

Before conducting the field sampling, the citizen volunteers were required to complete a training program consisting of three specific online courses: one focusing on the use of the iNaturalist app, a second course centered on IAPS in Catalonia, and a third one dedicated to the identification and monitoring of IAPS. Additionally, it was necessary for volunteers to take part in field excursions organized by the project's professionals, during which they visited different transects to familiarize themselves with the IAPS of the Costa Brava region and learn how to effectively identify and monitor these plants.

The volunteers were provided with a variety of resources aimed at facilitating the monitoring of their chosen transects to supplement their previous training. These resources included: (1) species-specific sheets containing information on invasion status, morphological and ecological characteristics, and guidance to differentiate invasive plants from similar species (https://lifemedcliffs.org/en/context/invasive-flora); (2) a transect-monitoring protocol outlining the specific data to be recorded for each iNaturalist observation (Gómez-Bellver et al. 2022); and (3) dichotomous keys for identifying the main invasive plants of the LIFE medCLIFFS project (Anonymous 2022). These resources were accompanied by visual aids such as graphics and photos, which were provided to volunteers both physically and digitally.

Volunteer Network Methodology for Sampling and Recording in the iNaturalist App

The project area was divided into five discrete regions: Costa Brava North (N), Costa Brava Center-North (CN), Costa Brava Center (C), Costa Brava Center-South (CS), and Costa Brava South (S). Each region is surveyed using approximately 1-km-long transects (Figure 1). The transects were defined by the project staff and are surveyed annually by volunteer citizens, who must walk along the transect and record all IAPS present from a predefined list of 33 (https://lifemedcliffs.org/en/context/invasive-flora) using the iNaturalist app, within a buffer area ca. 5-m wide. The selection of the 33 monitored species was based on three criteria: (1) species listed as invasive in the Spanish regulations (METDC 2024), (2) species not formally cataloged but identified as invasive in the study area through scientific evidence and expert opinion, and (3) species observed as naturalized (i.e., established but not yet invasive) in the Costa Brava with invasive potential. For the last ones

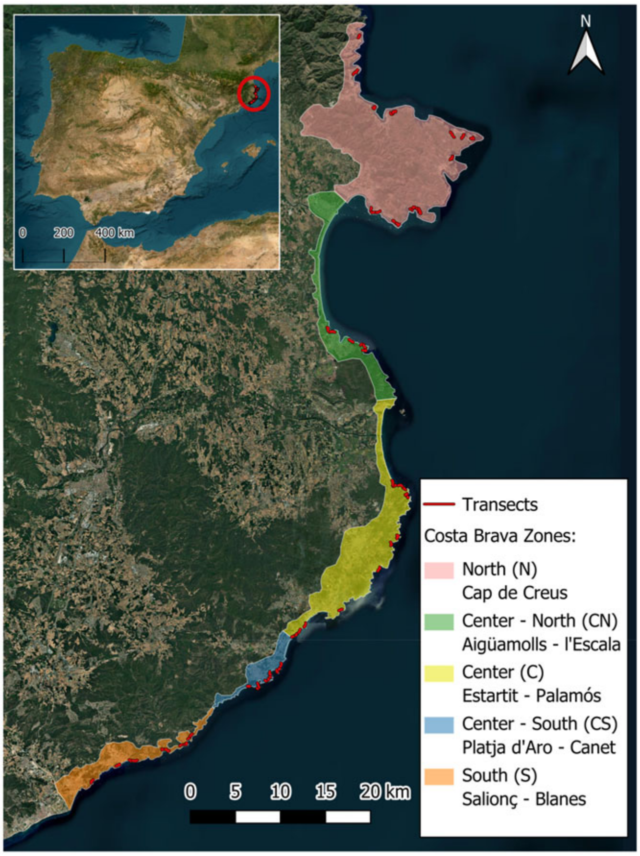

Figure 1. Study area and location of transects surveyed by citizen volunteers.

Table 1. Indicators for volunteers to fill out in each iNaturalist observation form.

Topics[a]	Monitoring protocol instruction
Transect code*	Indicate the transect chosen from an alphanumeric code list.
Area occupied*	Select the occupied area of the population based on the following categories: less than 1 m^2, between 1 and 10 m^2, between 10 and 20 m^2, or more than 20 m^2.
Presence of seedlings or young plants*	Specify whether there are recently germinated specimens (seedlings), propagules, or immature plants (yes/no).
Presence of vegetative adult plants*	Specify whether there are adult plants without flowers and/or fruits (yes/no).
Presence of sexually reproductive adult plants*	Specify whether there are adult plants with flowers and/or fruits (yes/no).
Presence of senescent or death plants*	Specify whether there are senescent or death plants (yes/no).
Population size	Whenever feasible, count the total number of individuals. If it is not possible (due to a very high population size, for example), you could estimate the number of individuals. This field is optional.
Notes	Make a note of the aspects that you consider important to incorporate.

[a]An asterisk (*) indicates a mandatory field.

(naturalized species with invasive potential), it is essential to monitor their evolution closely. Each transect is monitored by volunteers working in pairs to ensure and enhance the accuracy of sampling, as well as for safety reasons. However, only one volunteer of each pair records the observations in the iNaturalist app.

Every observation corresponds to a wild (i.e., not cultivated) population of an alien plant, which is recorded in the LmVN iNaturalist project (iNaturalist 2023b). Populations are defined as groups of individuals (or single individuals) separated by a minimum distance of 20 m from contiguous individuals of the same species. The volunteers are required to capture a minimum of three images depicting the habitat, the overall plant, and a relevant characteristic of the plant in accordance with the guidelines proposed by López-Guillén et al. (2024). Additionally, with each observation, they must also fill out a form included in the iNaturalist project, providing details on the elements specified in Table 1, following the instructions outlined in the monitoring protocol. It is important to emphasize that all mandatory fields consist of categorical choices to simplify data collection for nonexpert volunteers. Finally, every observation is reviewed and verified by the professional project staff, who provide feedback to volunteers when necessary. This verification ensures correct taxonomic identification and that all the form fields are correctly filled out.

Between January and October of 2023, a total of 78 volunteers collected data from 59 transects (out of a total of 106), producing 889 observations of 25 species. However, for illustrative purposes in this study, only those species with ≥20 observed populations were selected to do our analyses for testing our method, that is, nine species: maguey (*Agave americana* L.), giant reed (*Arundo donax* L.), ice plant (*Carpobrotus* spp.), climbing saltbush [*Chenopodium nutans* (R. Br.) S. Fuentes & Borsch; syn.: *Einadia nutans* (R. Br.) A.J. Scott], hoary stock [*Matthiola incana* (L.) W.T. Aiton], heartleaf ice plant (*Mesembryanthemum cordifolium* L. f.), barbary fig [*Opuntia ficus-indica* (L.) Mill.], Japanese pittosporum (*Pittosporum tobira* W.T. Aiton), and creeping groundsel (*Senecio angulatus* L. f.). We considered *Carpobrotus* spp. as a single entity, given that the two species traditionally regarded as present in Europe [*Carpobrotus acinaciformis* (L.) L. Bolus and *Carpobrotus edulis* (L.) N.E. Br.] very often hybridize, resulting in many intermediate forms that resemble *C. acinaciformis* (i.e., often referred to as *C.* aff. *acinaciformis*). Thus, some authors—with whom we agree—suggest that these two species together with their hybrids and potential hybrid swarms should be referred to as the *C. edulis*–*C. acinaciformis* complex (Campoy et al. 2018). The final dataset with these nine species comprised 59 transects and 695 observations.

Method for IAPS Prioritization

Thanks to the project's setup within iNaturalist, each verified observation in the LIFE medCLIFFS project corresponds to a population that contains information on the dynamics of the individuals present. These data enable the identification of many life stages within a population, including seedlings/young plants, vegetative adults, reproductive adults, and senescent/dead specimens, in any possible combination (Figure 2A). Although the number of individuals at each stage is not specified (the volunteers collect presence/absence data on life stages, and providing the number of individuals is not mandatory or always feasible), the basic life stage information collected by volunteers is highly informative, because it permits us to infer a population's behavior (Figure 2B), which can be associated with establishment.

Three broad categories were established based on the life stages observed in a given population: (1) propagative behavior, which comprises populations that consistently exhibit the presence of seedlings or young plants, while lacking senescent or deceased individuals; (2) senescent behavior, which includes populations

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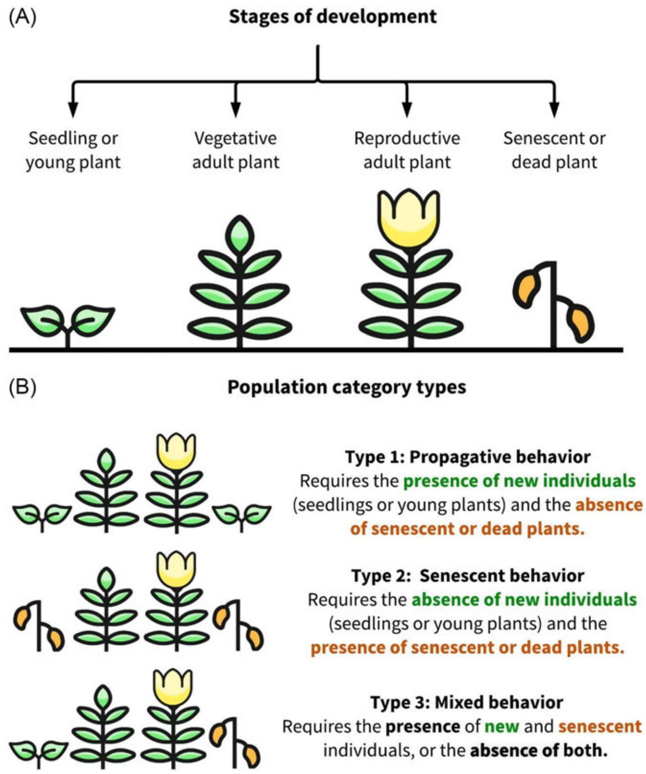

Figure 2. Method of classification of observations made by citizen volunteers in iNaturalist. (A) Developmental stages. Volunteers must indicate "yes" or "no" for the presence of four developmental stages: young plants, vegetative adults, reproductive adults, and senescent individuals. (B) Population category types. Each observation is classified into one of the three categories based on volunteer form responses.

that consistently exhibit the presence of senescent or deceased plants, whereas seedlings or young plants are absent; and (3) mixed behavior, showing the presence of both young and senescent individuals, or the absence of both (Figure 2B).

Following the classification of the data collected by the LmVN, matrices were created to represent the rate of observations per transect and the proportion of observations in each population dynamics category (propagative, senescent, or mixed behavior) for each species, both across the entire Costa Brava and for each of its regions. These proportions can then be used to generate heat maps, visually representing the state of the IAPS populations under evaluation.

The kind of information collected (rate of observations and proportion of observations in each population dynamics category) would make our method highly valuable for EDRR, as it allows us to quickly identify the priority species in EDRR (i.e., those species that have low observation ratios—they are probably still on the left side of the invasion curve—but that are exhibiting propagative behavior). The participation of volunteers, in addition, is of great benefit for EDRR, as more people on the ground increases the probability of finding IAPS (i.e., IAPS can be detected earlier).

Results and Discussion

Practical Outcomes of the First Year of IAPS Monitoring of the LIFE medCLIFFS LmVN

The regions of the Costa Brava with the highest ratio of observations per transect were CS and C, whereas S, CN, and N exhibited comparatively lower ratios (Table 2). The heat map in

Table 2. Number of transects, observations, and the rate of observations per transect for each region and the total count for the study area.

Region	No. of transects	No. of observations	Rate of observations per transect
Costa Brava S	11	96	8.73
Costa Brava CS	10	194	19.40
Costa Brava C	14	229	16.36
Costa Brava CN	6	30	5.00
Costa Brava N	18	146	8.11
Total	59	695	11.78

Figure 3 illustrates the ratio of observations per transect for the nine alien species recorded across the five Costa Brava sampling regions. Overall, this diagram reveals that nearly all species are present in all regions, with the exception of *C. nutans*, *O. ficus-indica,* and *S. angulatus*. Based on this ratio, three regions (CS, C, and N) contain species with more than three observations per transect (Figure 3).

It should be noted that while the N region, encompassing the Cap de Creus Natural Park, had the highest number of monitored transects, it did not yield a correspondingly high number of observations. The observed ratios in this region were generally low, except for *Carpobrotus* spp. and *O. ficus-indica* (2.44 and 3.88, respectively), both of which are targeted for control measures within the Cap de Creus Natural Park under the LIFE medCLIFFS project. These results indicate that the selection of species for control measures within the project has been appropriate. This is the first time that *Opuntia* spp. (including *O. ficus-indica* but also erect prickly pear [*O. stricta* (Haw.) Haw.] and desert prickly pear [*O. engelmannii* Salm-Dyck ex Engelm.]) will be managed for control purposes using chemical and biological methods, while control programs (manual/mechanical) aimed at limiting *Carpobrotus* spp. populations within the Natural Park have been ongoing since 2009 (Gómez et al. 2010).

Surprisingly, the most problematic species according to Figure 3 is *P. tobira* (with a ratio of nearly three), making it the most abundant species in all regions except N. Despite this, *P. tobira* is not listed as invasive in any of the official catalogs relevant to the Costa Brava (i.e., neither in the Spanish invasive alien species regulation [METDC 2024] nor in the European one [EC 2022]).

As can be seen in Figure 4A, the vast majority of the species are showing a trend that can be cautiously defined as of certain "demographic growth," as the category with the highest percentage is mixed behavior, followed by propagative behavior and, with much lower percentages, by senescent behavior (Table 3). The only species showing a considerable proportion of senescent populations (which is larger than that of propagative ones) are *O. ficus-indica* (propagative: 15%; mixed: 53%; senescent: 33%) and *Carpobrotus* spp. (propagative: 18%; mixed: 62%; senescent: 19%). In the case of *O. ficus-indica*, the high mortality rates could be linked to the fact that the species has been infested by *Dactylopius opuntiae* in recent years, and in the N region, this cochineal has been used for the biological control of this cacti since 2023 (Figure 5A). In contrast, we believe that the relatively high percentage of senescent populations of *Carpobrotus* spp. may be due to the extremely high temperatures experienced in the last two summers in the study area, which withered large parts of the individuals (Figure 5B). The relatively high percentage of senescent populations observed in *A. americana* (20%) is likely due to a pest, as in the case of *O. ficus-indica*. The agave weevil (*Scyphophorus acupunctatus*) has been severely affecting this species in the Costa

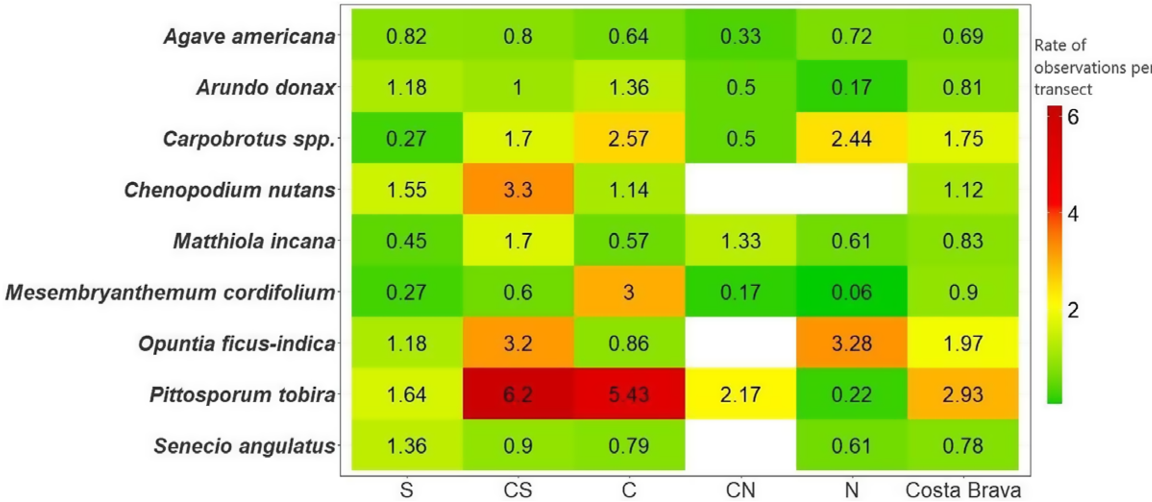

Figure 3. Heat map of the rate of observations per transect for species in each Costa Brava region: S, Costa Brava South; CS, Costa Brava Center-South; C, Costa Brava Center; CN, Costa Brava Center-North; N, Costa Brava North. The rightmost column contains the values for the Costa Brava as a whole.

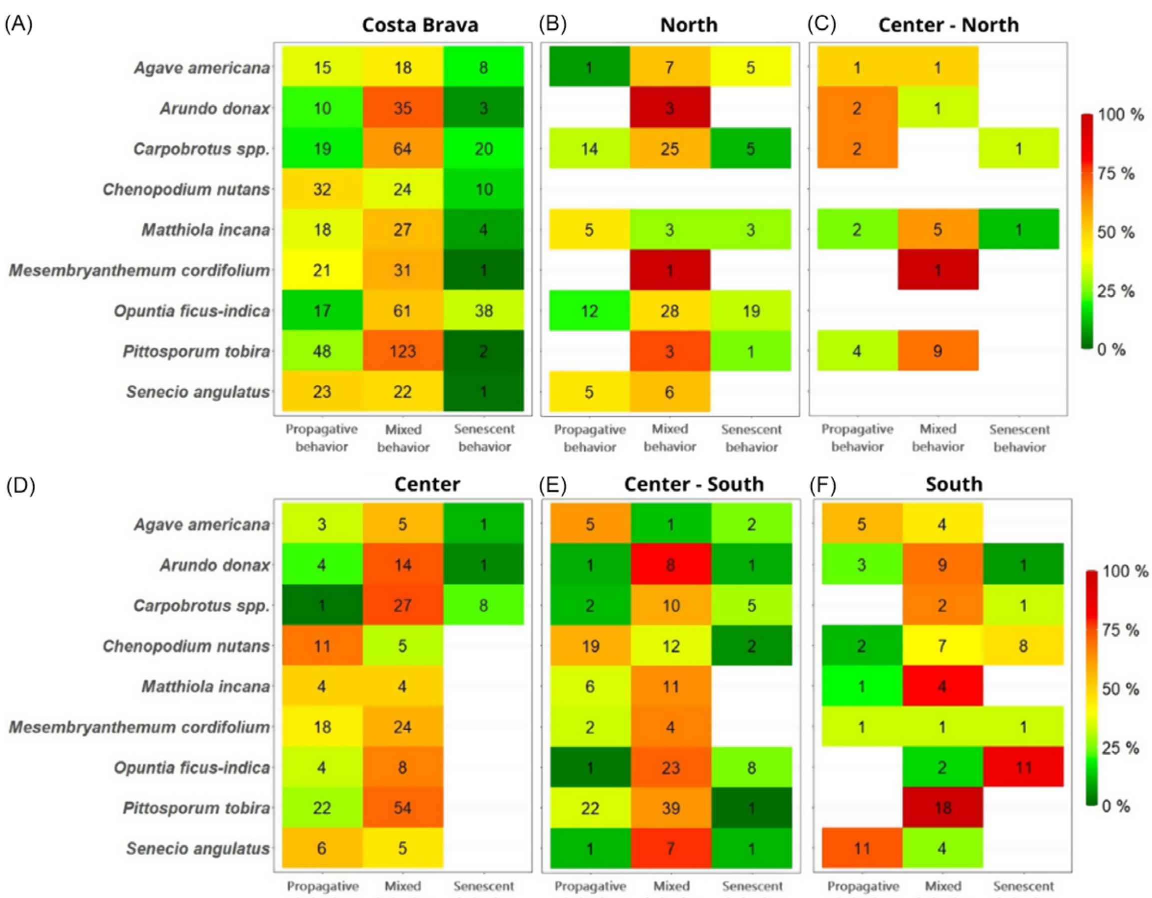

Figure 4. Heat map with the proportion of species observations within the three categories defined, for the Costa Brava as a whole and for each of the five defined regions. Numbers inside each colored box represent the number of associated observations.

Brava (and throughout much of the Iberian Peninsula) since at least the 2010s (CG-B and JL-P, personal observations; Figure 5C).

Finally, it is worth noting that there are two cases where the percentage of populations with propagative behavior is higher than that of populations with mixed behavior (*C. nutans* and *S. angulatus*). Notably, these two species are the only ones introduced in the Costa Brava after 1970 (Gómez-Bellver 2023), and one could therefore hypothesize that their population dynamics are related to the condition of recent neophytes. These two species are likely still in their early stages of invasion,

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Table 3. Proportions for each of the categories of population dynamics considered (propagative behavior, mixed behavior, and senescent behavior) for the nine monitored plant species in the Costa Brava.

Species	Propagative behavior	Mixed behavior	Senescent behavior
Agave americana	0.37	0.44	0.20
Arundo donax	0.21	0.73	0.06
Carpobrotus spp.	0.18	0.62	0.19
Chenopodium nutans	0.48	0.36	0.15
Matthiola incana	0.37	0.55	0.08
Mesembryanthemum cordifolium	0.40	0.58	0.02
Opuntia ficus-indica	0.15	0.53	0.33
Pittosporum tobira	0.28	0.71	0.01
Senecio angulatus	0.50	0.48	0.02

when higher rates of population growth are necessary for a successful establishment (Sakai et al. 2001), and have not yet reached equilibrium with their environment (e.g., Foster et al. 2022).

Just as the results have been analyzed and discussed for the heat map of the entire Costa Brava, the same analysis can be extended to more restricted areas, as the regions delimited in this study (Figure 4B–F), or even at the level of individual transects if necessary. This will depend on the manager's needs for identifying problematic zones for specific species.

Although the results discussed in this article represent the initial findings from the first year of monitoring carried out by the LmVN, it is expected that the knowledge of IAPS in the region—and the management derived from it—will substantially improve

Figure 5. Examples of senescent observations. (A) *Opuntia ficus-indica* intentionally infected by *Dactylopius opuntiae* as part of the eradication measures implemented in the LIFE medCLIFFS project. Photo: AB-G. (B) Live *Carpobrotus* spp. with a withered part. Photo: AB-G. (C) *Agave americana* infected *Scyphophorus acupunctatus*. Photo: JL-P.

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in the coming years of the project. In conclusion, the presented work introduces a novel methodological approach to simplify and present large amounts of citizen science data intended to improve the efficiency of management decisions.

Advantages and Limitations of Our Method to Detect and Monitor Alien Plant Species with Invasive Potential

Biological invasions are among the most pressing ecological and conservation issues nowadays. In addition to raising public awareness of environmental concerns and reducing labor costs, citizen science projects have become essential tools for the detection and management of many exotic species (Crall et al. 2010; Dickinson et al. 2012; Encarnação et al. 2021; Gallo and Waitt 2011; Larson et al. 2020; Wallace et al. 2021) in different regions and at varying scales. Indeed, the trade-off between cost and effectiveness of citizen science data offers the potential for scientists to tackle research questions at large spatial and/or temporal scales (Belt and Krausman 2012; Brossard et al. 2005; Holck 2007; Levrel et al. 2010; Szabo et al. 2010). Despite this, part of the scientific community remains concerned about the accuracy of citizen science data, as it has been reported that the quality of these data has historically been more variable than professionally collected data (Belt and Krausman 2012; Harvey et al. 2002; Moyer-Horner et al. 2012; Uychiaoco et al. 2005). However, and as will be discussed further, there is evidence that citizen performance can be comparable to that of professionals or scientists (Canfield et al. 2002; Hoyer et al. 2001, 2012; Oldekop et al. 2011), provided that they receive proper supervision, volunteer training, and feedback, among other recommendations (Aceves-Bueno et al. 2017; López-Guillén et al. 2024).

In the specific case of the LIFE medCLIFFS project, the volunteer network was complemented by experts who provided supervision, references, training, and acknowledgment. Additionally, the mandatory fields were established as categorical factors to be selected within a form setting on iNaturalist, using a multiple-choice format that has two primary repercussions. The first is the simplicity of the data produced, which is based on the presence or absence of features and does not take into consideration the abundances linked to each developmental stage of each population. The second one is the reduction in the difficulty of sampling for citizen volunteers, as well as the acquisition of a more consistent, homogeneous, and manageable database for researchers and managers. In contrast to projects focused on sampling endangered species or populations (Soroye et al. 2022), the level of detail of data on invasive alien species generally does not have legal implications (although there would be legal effects if data are used as a basis for listing these species as invasive and prohibiting their sale). Moreover, the sampling procedure does not provide risks to the species that are being investigated, which makes the task of designing the sampling and collecting data for citizen volunteers much easier.

Despite the simplicity of using categorical choices for most features that volunteers must record, our citizen science project (and the underlying methodology) is one of the few that goes beyond merely detecting new locations of alien plants, as is the case with most of the abovementioned citizen science projects. Until recently, most of the citizen science projects on invasive species were exclusively focused on reporting their presence. Crall et al. (2010) surveyed 128 citizen science programs of alien species of the United States, and while 95% of them collected data on species presence, only one-fifth recorded data on life stages. Although presence-focused projects are valuable, they typically do not provide outputs with direct control or management implications. Fortunately, there has been an emergence of citizen science projects in recent years that are specifically designed to provide data with direct applications on control and management measures. For example, the citizens using the BambApp recorded a series of traits (maximum height, maximum stem diameter, and size of the clump, as well as habitat type) aimed at helping public authorities to reevaluate the invasive potential of bamboo species (i.e., those included within the subfamily Bambusoideae) and regulate their commerce in northwest Italy (Pittarello et al. 2021).

The method is also applicable to species with a low number of observations (i.e., <20), which makes it useful for EDRR. For this purpose, the data obtained by the LmON are of great importance, as this network is composed of hundreds of observers on the ground (about 600 as of September 2024). New populations of the predefined list of 33 species, or even new species detected in the area by the LmON (as this network includes 184 species), can be incorporated into the annual surveys carried out by the LmVN. However, it must be acknowledged that interpretation problems can arise with species or regions with a low number of observations when generating heat maps due to reliance on proportion matrices. For example, consider a region where 100% of the populations exhibit propagative behavior, but this 100% is actually attributed to only two populations in the area. In contrast, another region may have 70% of the populations displaying this behavior of a total of 10 surveyed populations. In this regard, it is necessary to present the information as completely as possible, because the methodology can serve different purposes (such as selecting the most widespread species—case 2—or, alternatively, selecting species with a low number of populations to prevent their spread—case 1). If the count of observations linked to each square is shown in the diagram, it is possible to see the actual number of associated observations when calculating the percentage (as shown in Figure 4). Alternatively, tables can be incorporated to display the count of partial and total observations along with the proportions represented (as shown in Table 3), providing a more accurate interpretation of the obtained result and avoiding management decisions that are not fully informed.

The approach we developed enables us to effectively organize a large amount of data (in this case, 695 observations) into heat maps. These heat maps provide a concise and visually intuitive representation, facilitating the identification of alien species and/or areas that require monitoring and intervention. Even so, as mentioned earlier, a limitation of this methodology is the inability to determine abundances of each developmental stage within populations exhibiting mixed behavior. For example, a population might have a high density of young plants and a very low density of senescent ones. It should be taken into account that our methodology is not a demographic study sensu stricto, which would require a much more complex approach that includes monitoring individuals throughout the life cycle to estimate population growth rates and identify those life-cycle stages that most influence population trends. Nonetheless, the relatively simple concept of propagative behavior serves as a quick resource to assist in the initial prioritization of species and regions based on their ability to establish growing populations, which is associated with a greater risk of invasion compared with populations where some level of natural decay of individuals is noticeable. Although we do not have data proving that the presence of seedlings/juveniles (i.e., populations with higher propagule pressure) increases the likelihood of establishment (as our observations

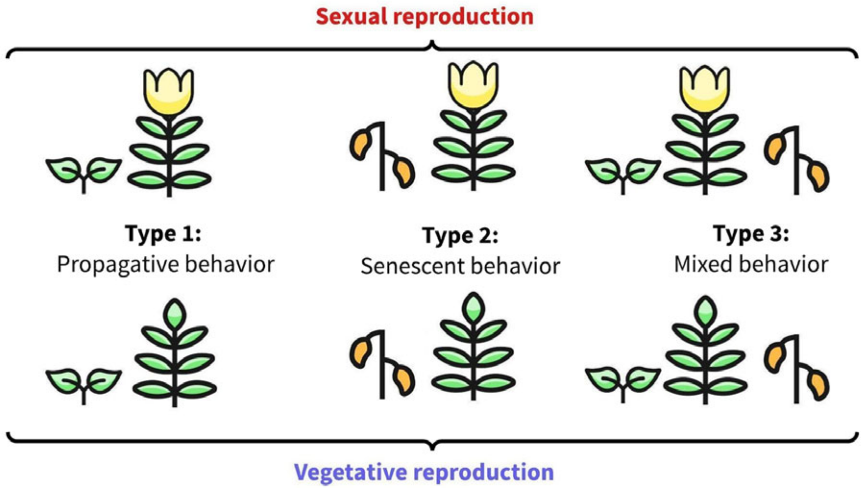

Figure 6. Population subcategory types: type 1, propagative behavior; type 2, senescent behavior; type 3, mixed behavior. The three categories defined in Figure 2 could be separated into two subcategories according to the presence of reproductive adults (with flowers and/or fruits) when necessary.

span only 1 yr), the link between propagule pressure and establishment success is widely acknowledged (Carr et al. 2019; Colautti et al. 2006; Simberloff 2009). Our method, unfortunately, can only be applied to perennial plants, as it might not be feasible to classify a given population of an annual species into any of the three behavioral categories. However, this limitation does not notably reduce the method's usefulness, as invasive alien plants are typically perennial compared with noninvasive ones (e.g., Huang et al. 2009; Korpelainen and Pietiläinen 2023; Sutherland 2004). In fact, all 33 plant species under monitoring (chosen based on catalogs, scientific evidence, and expert opinion; Materials and Methods), which were regarded as the most invasive or having the most invasive potential in the study area (https://lifemedcliffs.org/en/context/invasive-flora), have a perennial life cycle. This does not mean that there are no annual alien plants in the region (Aymerich and Sáez 2019).

Given the limitations, it is important to keep in mind that this kind of initiative enables the collection of a substantial volume of data through collaboration with residents of many communities in the region. Beyond challenges associated with data quality and methodology, there is also the need to maintain participant motivation, raise awareness, and continuously recruit citizen volunteers to avoid information gaps. For instance, within the LIFE medCLIFFS project, several strategies are designed to keep volunteers engaged. First, there is an incentive system that rewards those who make the most complete and accurate observations (e.g., including high-resolution photographs and with all fields correctly filled in). In addition, periodic meetings between volunteers, project managers, and technicians are held (mostly on the ground but also in the form of dissemination workshops), and feedback is provided through social media (e.g., there is a Telegram channel for answering volunteers' queries).

Ensuring the completion of a monitoring program—and avoiding information gaps—is of particular relevance, as for most cases it seems much more reliable to recruit a team of citizen scientists rather than depend solely on professional researchers for invasive species detection. There are at least two reasons that make volunteer participation essential, especially for plant research and management. The first one is the sharp decline in the number of professional botanists globally in recent years, as clearly described in Crisci et al. (2020). As an illustrative example, the Department of Botany of the Faculty of Pharmacy at Barcelona University has lost over three-quarters of its scientific staff in the past two decades. The second reason is the lack of attractiveness of most fieldwork-based investigations compared with other types of studies (e.g., genetics) for the professional botanists, mostly due to the pressure to publish in high-impact factor journals (Ríos-Saldaña et al. 2018).

In the context of a shortage (or lack of interest) of professional botanists, the simplicity of the collected data regarding population dynamics becomes an advantage in a citizen science project such as the one presented here. Moreover, the accuracy of the data generated by volunteers is often comparable to that of professional botanists, even for relatively complex measures. For example, volunteers correctly identified plant phenophases (emerging leaves, unfolded leaves, open flowers, full flowers, and ripe fruits) in most cases (91%) in a citizen science project within the USA National Phenology Network (Fuccillo et al. 2015). However, it is important to note that the participants in this network attended a 6-h training. Certainly, previous training is crucial for the good performance of the citizen scientists and for ensuring the reliability of the collected data. Salomé-Díaz et al. (2023) compared the degree of reliability in the phenological classification (initial growth, immature flower, mature flower, and dry fruit) between trained and untrained volunteers for two invasive species [*Leonotis nepetifolia* (L.) R. Br. and *Nicotiana glauca* Graham] in Mexico; the level of reliability was significantly higher among trained volunteers compared with untrained volunteers, and for most phenophases the performance of trained volunteers was nearly equal to that of expert scientists.

Broadening Our Proposal: Expanded Categories for Sexually Reproducing Species

A last advantage of our method is that the observations can be made year-round, as the construction of heat maps does not distinguish between vegetative and reproductive adult individuals. Nevertheless, for strictly or partially sexually reproducing species (e.g., *P. tobira*), populations with flowers and fruits have a higher reproductive potential than those with only vegetative adults (which cannot reproduce). In such cases, the previously mentioned categorization based on the presence of young and senescent plants

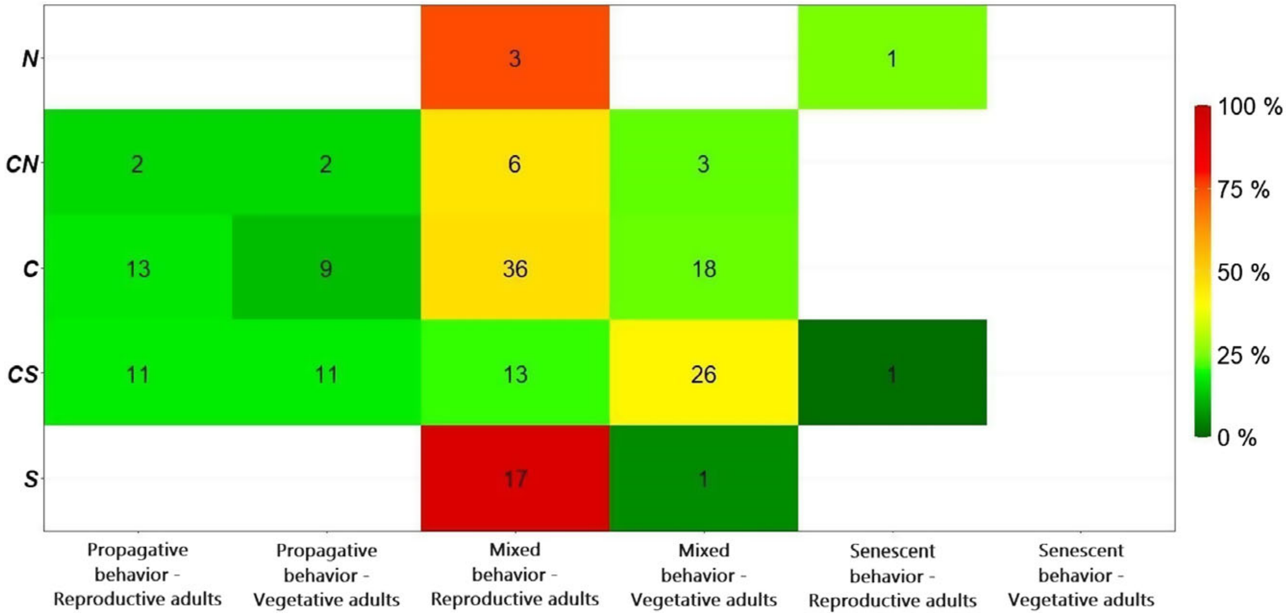

Figure 7. Heat map with the proportion of *Pittosporum tobira* observations within each subcategory in the five defined regions of the Costa Brava: C, Costa Brava Center; CN, Costa Brava Center-North; CS, Costa Brava Center-South; N, Costa Brava North; S, Costa Brava South. Each colored square in a region represents the percentage of one of the six possible subcategories of population dynamics, adding up to 100% across each row. Numbers inside each square represent the number of associated observations.

can be expanded to gain a more detailed knowledge on the population dynamics of the observed populations. By adding a second subdivision according to the presence/absence of sexually reproductive structures (flowers or fruits) in adult plants, one can categorize a given plant population in six subcategories (Figure 6). In contrast, applying this subclassification for species with exclusively asexual reproduction is not always feasible, as it is not possible to distinguish between reproductive and non-reproductive individuals in some cases (e.g., rhizome fragmentation). For example, *A. donax* does not reproduce sexually outside its native area (Jiménez-Ruiz et al. 2021), making it impossible to visually ascertain whether a given population is undergoing asexual reproduction. In other cases of asexual reproduction, this subcategorization can be applied (e.g., for asexual reproduction through buds, bulbils, or plantlets); however, as with sexually reproducing plants, the observations should be made during the reproductive season, which is when the volunteers of the LIFE medCLIFFS project are encouraged to make their observations.

Figure 7 provides a specific example of the species *P. tobira* to demonstrate the use of subcategories in cases where a species exhibits sexual reproduction in its invasive range. It also illustrates a detailed analysis of a particular species of interest with a high number of observations ($N = 173$). The heat map displays the proportion of observations across subcategories and regions, with each colored square in a zone representing a percentage of one of the six possible subcategories that adds up to 100% across each row. Thus, it is evident that *P. tobira* is present in all five regions of the Costa Brava, albeit with contrasting percentages across the different subcategories of population dynamics. Notably, the S and N regions of Costa Brava are the only ones lacking propagative behavior. Despite this, both regions contain reproductive adults (with flowers and fruits), indicating that these populations are not exempt from the (theoretical) production of offspring by seeds. In addition, there is a higher concentration of populations in the reproductive mixed behavior subcategory in the southern zone.

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