Kalanchoe × *houghtonii* and its parental species (*K. daigremontiana* and *K. tubiflora*): three newcomers quickly expanding in the Mediterranean Basin

Mònica Utjés, Laura Mena, Neus Nualart & Jordi López-Pujol*

Botanic Institute of Barcelona (IBB, CSIC-Ajuntament de Barcelona), Pg. del Migdia, s/n, 08038 Barcelona, Spain

*Corresponding autor: jlopezpu@gmail.com; jlopez@ibb.csic.es

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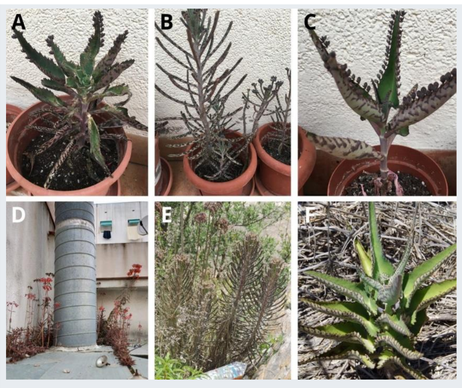
INTRODUCTION

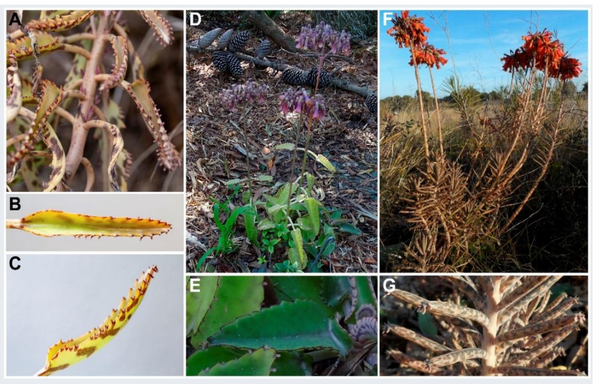
Global biodiversity is increasingly threatened due to the aggravation of climate change and globalization, which accelerate phenomena such as the reduction and fragmentation of habitats. Therefore, the arrival and establishment of invasive species is favored. Delimiting the present distribution area of invasive alien species and analyzing ecological niches are essential tools to identify their degree of invasion and propose management actions to stop their expansion.

Kalanchoe* × *houghtonii* (Crassulaceae)** is an artificial hybrid created in the 1930s in the United States by experimental crossings between ***K. daigremontiana and ***K. tubiflora***, two species endemic to Madagascar. While the three taxa are well-known invaders in some parts of the world (e.g., in Australia, South Africa, and the United States), they are seldom reported as problematic in the Mediterranean basin, most likely because of their recent introduction (1990s, in the Iberian Peninsula).

Ornamental horticulture has become the major introduction pathway of invasive alien plants. Their attractiveness, easy cultivation and reproduction, and resistance to drought make plants of genus *Kalanchoe* the perfect ones for horticulture. Thanks to its large colonizing capacity, the hybrid (and the parental species to a lesser extent) soon escaped from cultivation and quicky spread in many parts of the world.



Cultivated specimens: A – *Kalanchoe* × *houghtonii*, B – *K. tubiflora* & C – *K. daigremontiana* (photos by Laura Mena). **Wild specimens:** D – *Kalanchoe* × *houghtonii* in Barcelona, Spain (photo by Neus Nualart), E – *K. tubiflora* in Texas, EUA (photo by Eric Knight, iNaturalist) & F – *K. daigremontiana* in Querétaro, México (photo by Sandino Guerrero, iNaturalist).



Differences between the hybrid and its parental species: A, B, C – *Kalanchoe* × *houghtonii* in Parc del Guinardó, Barcelona (Catalonia, Spain), detail of the leaves generally attenuated on the petiole and bulbils distributed on the margins of the leaf blades (photos by Mònica Utjés); D, E – *K. daigremontiana* in Blanes (Catalonia, Spain), adult plant and detail of the leaf with basal "wings" (photos by Jordi López-Pujol); F, G – *K. tubiflora* in el Vendrell (Catalonia, Spain) with subcylindrical leaves and bulbils restricted to the apex (photos by Jordi López-Pujol).

The three taxa show **similar leaf morphology**, particularly between *K.* × *houghtonii* with one of its parentals (*K. daigremontiana*). This has caused a high rate of confusions between these two taxa, also incremented by the lack of a formal description of the hybrid until 2006. *Kalanchoe tubiflora* has typical **subcylindrical leaves** and bulbils restricted to the apex zone.

Differences between hybrid and *K. daigremontiana* are only in the shape and position of the leaves:

(1) In *Kalanchoe* × *houghtonii* leaves are petiolate, with the **leaf blade simple**, from triangular to narrowly lanceolate. Bulbils are distributed on the margins nearly the whole leaf blade.

(2) The leaves of *K. daigremontiana* are peltate with **basal blade 'wings'** stretching beyond point of petiole attachment for up to ± 2 cm, smooth, petiolate, ± flattened above and below to strongly guttered. Bulbils are distributed as the hybrid.

OBJECTIVE

The **aim** of this study is to provide updated distribution maps for the whole Mediterranean Basin and neighboring regions for the three *Kalanchoe* taxa cited above. Specifically, we are:

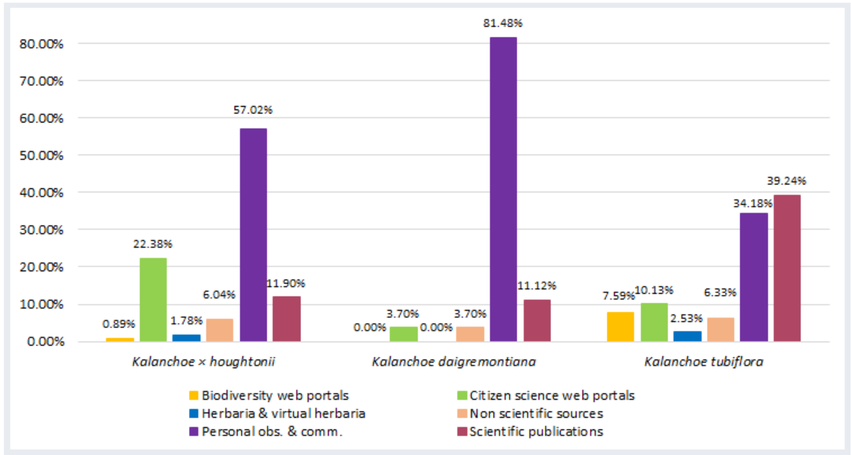
(1) exploring the **geographic distribution pattern** of the hybrid and its parental species.

(2) tracking their **temporal and spatial colonization history.**

MATERIALS AND METHODS

An extensive literature search was done for produce the distribution maps of *Kalanchoe* × *houghtonii* and its parental species (*K. daigremontiana* and *K. tubiflora*) for the whole Mediterranean Basin and neighboring regions. Search for localities included different sources:

- biodiversity web portals (such as GBIF)
- herbaria (including virtual herbaria)
- personal observations and communications (our research group, **XenoPlants**, is studying these taxa since 2014)
- citizen science web portals (e.g., iNaturalist)
- scientific publications
- non-scientific sources (such as photo-upload tools, social media platforms, and personal blogs)

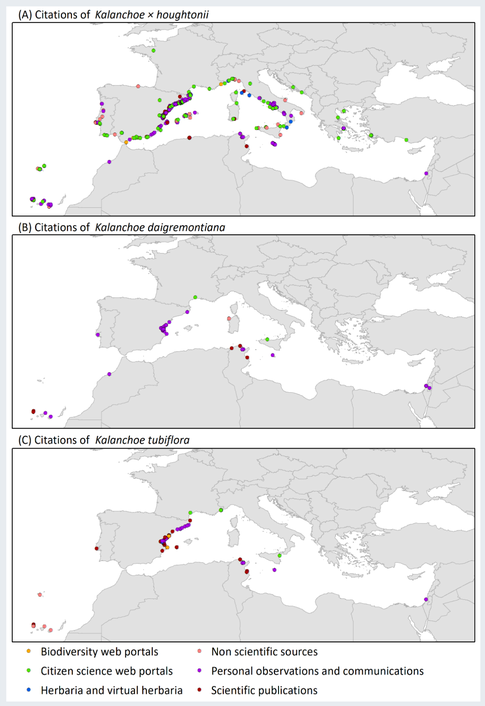


Graphic representation in percentage (%) of the occurrences according to the **sources of information**.

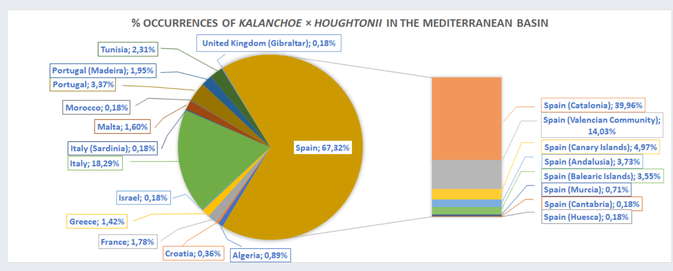
All occurrences were exhaustively **validated** one by one, keeping only those with precise location and photographs of the specimen in the wild or on herbaria sheets, to avoid confusion between taxa. A total of **696 occurrences** passed the validation criteria.

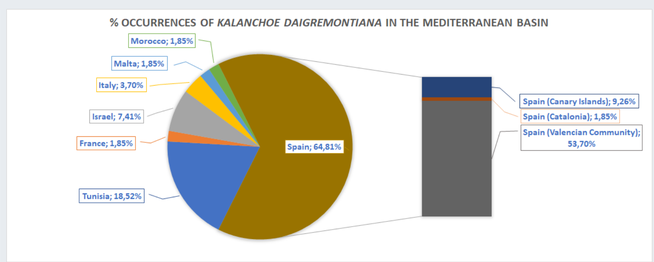
RESULTS AND DISCUSSION

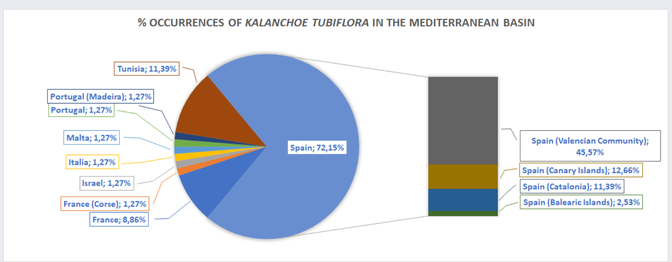
Distribution maps of *K.* × *houghtonii* and its parental species in the Mediterranean Basin and neighboring areas



Distribution maps of *K.* × *houghtonii* and its parental species in the Mediterranean Basin and neighboring areas.







Graphic representations in percentage (%) of **occurrences by countries.**

The 696 validated occurrences are distributed as follows:

- *K.* × *houghtonii*, 563 occurrences
- *K. daigremontiana*, 54 occurrences
- *K. tubiflora*, 79 occurrences

Distribution maps reveal that in some parts of the Mediterranean Basin (**particularly Italy and Spain**) the three taxa are well represented.

Personal observations and communications are the dominant source of occurrences in these countries, and allowed us to compile 60-80% of them (but to a lesser extent for *Kalanchoe tubiflora,* 34.18%).

Citizen science web portals provided around 25% of the total occurrences for the hybrid (and 10.13% for *K. tubiflora* and only 3.70% for *K. daigremontiana*), which means an important input to our research.

Other sources (biodiversity web portals, herbaria, scientific publications and non-scientific publications) have also provided occurrence data.

Most of *XenoPlants* fieldwork research is centered in our geographical area (the Iberian Peninsula and the Western Mediterranean basin), although our scope is worldwide. Graphic representation of the percentage of occurrences reveals the important task developed. Our research allowed us to compile around 65-75% of the total occurrences in the Iberian Peninsula, especially for Catalonia and the Valencian Community.

The **lack of records in many Mediterranean countries** (such as Albania, Bosnia and Herzegovina, Croatia, Egypt, Libya or Syria) may be due to:

(1) these taxa have actually not reached these countries, perhaps because their use as ornamentals is not known there

(2) they are actually there but they have not been detected, likely because insufficient fieldwork or taxonomic ignorance

For these and other invasive alien species, it is of paramount importance to conduct field surveys to ensure early detection and at the same time to monitor the expansion of the alien flora. Early detection and inventorying are the best method for controlling alien species, as it may allow their eradication before they become established.

Judging the distribution maps for the three taxa, it is clear that **the hybrid has expanded more than its parental species in the Mediterranean Basin**. This can be due to:

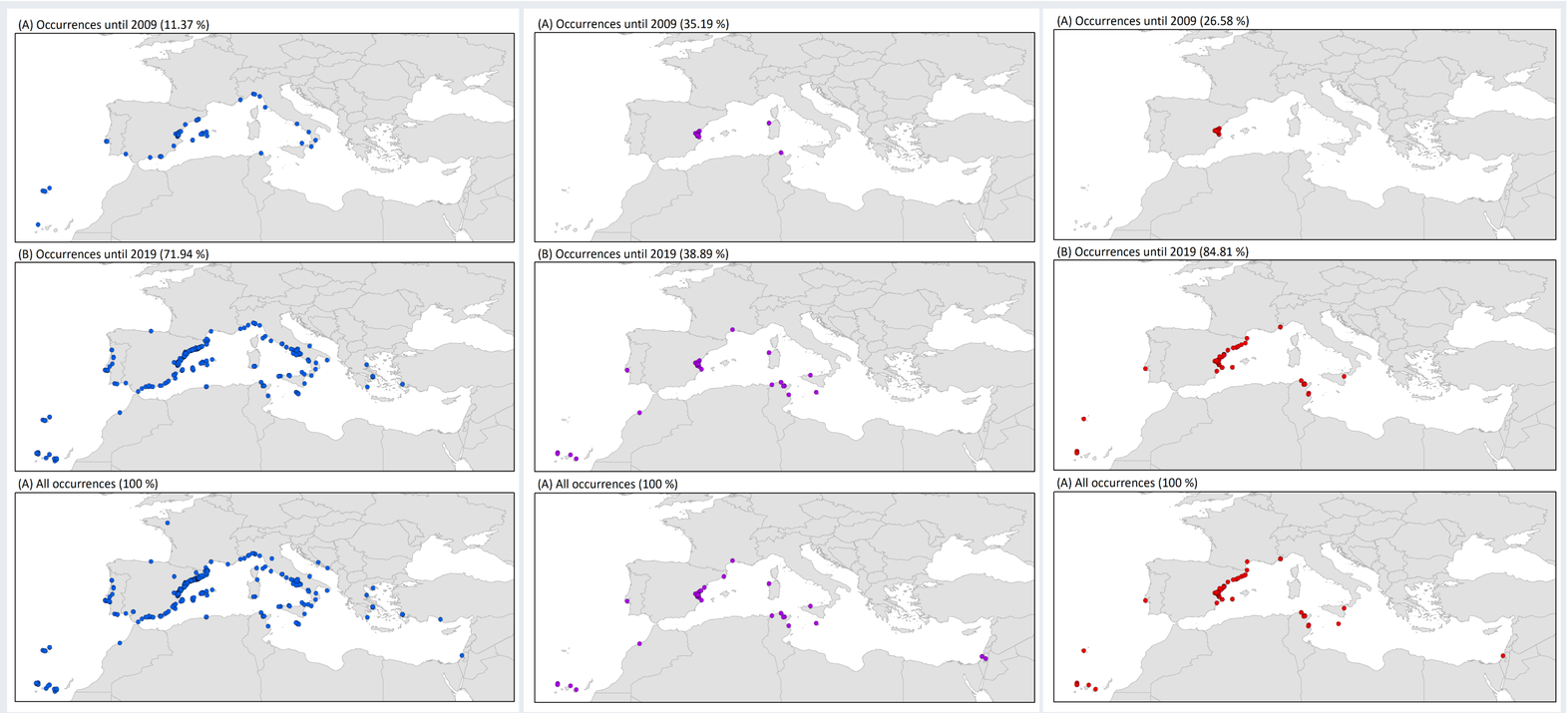
(1) the fact that the species is often cultivated in private gardens, due to its taxonomic confusion with *K. daigremontiana*, a species with alleged nearly "miraculous" healing properties

(2) a higher expansion capability due to its hybrid nature (i.e. hybrid vigor)

Kalanchoe tubiflora, despite being a species that is rarely cultivated, may compensate its expansion through a **higher incidence of sexual reproduction**: previous studies have shown that the successful germination of *K. tubiflora* seeds (57 %) is higher than that of *K.* × *houghtonii* (11.9%).

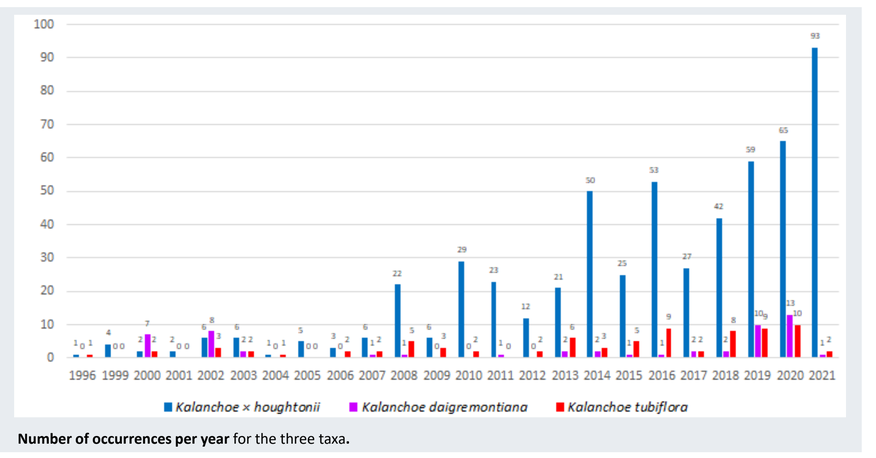
The lower geographic expansion of *K. daigremontiana* may respond to a **lower expansion capacity** (according to our observations, in equal conditions, *K. daigremontiana* has higher mortality rates and lower propagule production than the other two *Kalanchoe* taxa).

Temporal and spatial colonization history of *K.* × *houghtonii* and its parental species



Representation of the temporal and spatial expansion of the occurrences for the three taxa from (A) before the year 2009 to (C) today. Hybrid occurrences are represented in blue, *K. daigremontiana* in purple and *K. tubiflora* in red.

It was not until late 20th century when *Kalanchoe* × *houghtonii*, *K. daigremontiana* and *K. tubiflora* are firstly documented in the Mediterranean Basin. The first occurrences of *Kalanchoe* × *houghtonii* and *K. tubiflora* date from 1996, while the first observation of *K. daigremontiana* was in 2000. The first occurrences detected for the three taxa all come from the same area (the Valencian Community, Spain) and from the same observer (D. Guillot, botanist and taxonomist).



Number of occurrences per year for the three taxa.

The results conclude that:

(1) the **growth of observations is increasing exponentially in recent years**, coinciding with the emergence and consolidation of citizen science portals such as iNaturalist

(2) as the species appear to have entered Europe from the west, a pattern of expansion to the east is seen over time, which anticipates the **appearance of new localities in the eastern basin**

CONCLUSIONS

- As the taxa are expanding rather quickly, it is necessary to **make known the existence of these three species** and the real danger they represent to the Mediterranean ecosystems. Talks in schools, seminars at universities, informative leaflets on the street or information in garden centers, could be a beginning of an approach to improve the knowledge of the hybrid and its parental species.
- Differences observed respect to some results of previous studies on the hybrid highlight the urgency of **establishing control protocols on populations** of alien flora. Although *K.* × *houghtonii* is already behaving as a truly invasive species in some parts of the Mediterranean Basin (particularly Italy and Spain), the parental species should also be closely watched.
- To get further insights into the ability of these species to colonize new areas on the Mediterranean basin, and to improve the knowledge about their potential damage to ecosystems, **future studies** should include:
  (1) species distribution models (e.g. with MaxEnt)
  (2) ecological niche studies in E (environmental)-space
  (3) studies on fitness (e.g. propagule production, population viability, and seed germination)
  (4) genetic studies

This research is largely thanks to the science produced by citizens, who have shared their personal observations of *K.* x *houghtonii* or any of its parental species (*K. daigremontiana* or *K. tubiflora*) directly to us or by inputting them in citizen science web portals. Further research will be benefited from your own observations; so we will greatly appreciate your collaboration in biodiversity web portals as iNaturalist or sending us pictures and the geographical coordinates at kalanchoeibb@gmail.com

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