Biology and spread of the new alien species *Coreopsis grandiflora* (Asteraceae) in southern Switzerland

Brigitte Marazzi[1,2*], Sofia Mangili[1], Andreas Gygax[3] and Antoine Jousson[1,2]

[1] **Museo cantonale di storia naturale, Viale C. Cattaneo 4, 6900 Lugano, Switzerland**
[2] **Info Flora, c/o Museo cantonale di storia naturale, Viale C. Cattaneo 4, 6900 Lugano, Switzerland**
[3] **Info Flora, c/o Botanischer Garten, Altenbergrain 21, 3013 Bern, Switzerland**

**** brigitte.marazzi@ti.ch***

Abstract: *Coreopsis grandiflora* Hogg ex Sweet (Asteraceae) is an herbaceous perennial ornamental species from United States that arose to attention in 2019 in southern Switzerland. Plants were reported in sensitive river floodplain habitats in the Locarno area but at first identified as the similar *C. lanceolata*, already recognized in the Swiss flora. We documented the species using field surveys, photographs, and herbarium specimens. A key to identify *Coreopsis* in Switzerland is presented. Leaves are generally simple (undivided) and along the lower half of the stem in *C. lanceolata*; they are pinnate and also in the stem upper half in *C. grandiflora*. Almost all populations across the 14 surveyed municipalities corresponded to *C. grandiflora*. It is widespread at thermophilic sites along railroads, roadsides, in meadows, vineyards or ruderal sites, and also natural river floodplains. It flowers from May to September; seeds mature in few weeks and germinate in the same year. The observation of dense stands coupled with high number of seeds, suggests that *C. grandiflora* has a potentially invasive behavior, despite its limited vegetative reproduction and natural dispersal primarily over short distances. Human activities evidently contribute to its spread. Research is necessary to quantify negative impacts, especially in natural river floodplains, as the species could alter their dynamic. Active management is recommended to at least stop further spread. Hand pulling is effective to remove it from sensitive habitats.

Keywords: Canton Ticino, Early detection, Invasion, Neophyte, Ornamental species

Biologia ed espansione della nuova specie esotica *Coreopsis grandiflora* (Asteraceae) nella Svizzera meridionale

Riassunto esteso

Introduzione: *Coreopsis grandiflora* Hogg ex Sweet (Asteraceae) è una pianta erbacea perenne, coltivata come ornamentale e originaria degli Stati Uniti sud-orientali. Nel 2019 sono state osservate delle piante naturalizzate nelle zone golenali d'importanza nazionale del fiume Maggia nel Locarnese, inizialmente identificate come *Coreopsis lanceolata* L. In seguito a verifica sul campo da parte di esperti, le piante sono infine state identificate come *C. grandiflora*. Gli obbiettivi di questo studio sono 1) investigare la distribuzione geografica di *C. grandiflora* nella regione, 2) verificare l'identità tassonomica nei siti d'osservazione, 3) documentare gli aspetti sulla biologia e l'ecologia della specie (incluso un test di germinazione dei semi), 4) raccogliere e discutere le informazioni rilevanti per una valutazione rapida del potenziale d'invasione e 5) fornire delle raccomandazioni per la lotta e la gestione.

Materiali e metodi: Per identificare correttamente le specie sul terreno e fornire una descrizione botanica dettagliata di *C. grandiflora* sono state utilizzate varie opere botaniche, sia nord-americane sia europee. Per investigare la distribuzione locale, la biologia e l'ecologia della specie nel corso del 2021 sono state visitate le popolazioni di *Coreopsis* sp. nel Locarnese (conosciute e nuove), documentando i seguenti aspetti: biologia riproduttiva (riproduzione vegetativa, fenologia, impollinazione, vitalità e dispersione dei semi), tipo di habitat e crescita (formazione di popolamenti monospecifici densi o meno densi) e capacità rigenerative (reazione delle piante alle pratiche di gestione, come lo sfalcio). La vitalità dei semi è stata studiata con un test di germinazione preliminare. Per valutare se la specie presenta un comportamento (potenzialmente) invasivo sono state raccolte le informazioni necessarie secondo il catalogo dei criteri di Info Flora, basandosi sia sulle osservazioni fatte sul campo sia sulle informazioni presenti in letteratura.

Risultati e discussione: *Coreopsis grandiflora* ha foglie pennate, presenti anche nella metà superiore dello stelo, mentre in *C. lanceolata* le foglie sono generalmente semplici (non divise) e circoscritte nella metà inferiore dello stelo. *C. grandiflora* è stata identificata in tutte le popolazioni dei 14 comuni esaminati, tranne una. La specie è diffusa nei siti termofili lungo le ferrovie, ai bordi delle strade, nei prati, nei vigneti o nei siti ruderali, ma cresce anche nelle golene naturali dei fiumi. Fiorisce da maggio a settembre; i semi maturano in poche settimane e sono in grado di germinare nello stesso anno. L'osservazione di popolamenti densi e l'elevato numero di semi suggeriscono che *C. grandiflora* possa avere un comportamento potenzialmente invasivo, nonostante la sua limitata riproduzione vegetativa e la dispersione principalmente su brevi distanze. Le attività umane contribuiscono in modo evidente alla sua diffusione.

Conclusioni: *Coreopsis grandiflora* attualmente è ancora poco diffusa nel Cantone Ticino, concentrandosi nel Locarnese, ma una sua espansione è plausibile. Sono necessarie ricerche specifiche per quantificare gli impatti negativi di questa specie, soprattutto nelle zone golenali. Si raccomanda una gestione preventiva per fermare un'ulteriore espansione. La rimozione manuale (estirpazione) è un metodo efficace per eliminare i piccoli popolamenti dalle zone golenali.

Parole chiave: Cantone Ticino, Invasione, Neofita, Riconoscimento precoce, Specie ornamentale

INTRODUCTION

Southern Switzerland is known for its insubric climate, which allow many subtropical or even tropical plant species to grow in the most sheltered locations (MeteoSvizzera 2012). It belongs to the Insubric region that encompasses the area of the great lowland prealpine lakes on the southern side of the Alps in Canton Ticino (Switzerland), Piedmont and Lombardy (Italy), which display a rich exotic flora (Banfi & Galasso 2010, Schoenenberger et al. 2014). New casual or already established alien species are constantly discovered in the wild (e.g., Galasso & Banfi 2020; Mangili et al. 2020; Marazzi et al. 2021). In this study, we present *Coreopsis grandiflora* Hogg ex Sweet (Asteraceae), a new alien species from the southeastern United States that arose to attention in 2019 in Canton Ticino, adding to the North American *C. lanceolata* L., currently already recognized in the wild flora of Switzerland (Juillerat et al. 2017).

Coreopsis comprises 86 species of herbaceous annual or perennial plants and valued ornamentals, of which numerous varieties and cultivars are available commercially (Crawford et al. 2009). Its generic circumscription has long been difficult, mainly due to its similarities with the closely related but much larger genus *Bidens* L. (Crawford et al. 2009). The two genera are the largest of tribe Coreopsideae, in which the many studies attempting to disentangle phylogenetic relationships among the tribe's 24 genera have consistently retrieved *Bidens* to be polyphyletic within *Coreopsis* (e.g. Kim et al. 1999; Crawford et al. 2001, 2009; Kimball & Crawford 2004; Crawford & Mort 2005; Mort et al. 2008; Knope et al. 2020). However, a systematic revision including nomenclatural adjustments has yet to be published (cf. Knope et al. 2020). Therefore, in this study we remained conservative and used the current generic names.

In Central Europe, several ornamental *Coreopsis* species are cultivated, but only a handful appear to be reported in the wild. For example, in Germany, of at least a dozen cultivated species, only *C. grandiflora* and *C. lanceolata* have escaped (Jäger et al. 2007). In Italy, while *C. grandiflora* remains unreported in the wild, *C. lanceolata* is established, and another North American species, *C. tinctoria* L. is considered a casual alien (Pignatti et al. 2017-2019; Galasso et al. 2018, as *Bidens*). A similar pattern occurs with these species in France (MNHN & OFB 2003-2022). None of them is considered invasive in these countries. In Switzerland, in particular in the Locarno region, there has been a recent increase of *C. lanceolata* reports outside of gardens, although still in or next to urban areas. As the taxon was unexpectedly detected in the floodplains of national importance of the Maggia River nearby Locarno, the nature and conservation authorities of Canton Ticino prompted the present work, wondering about a potentially negative impact of this alien on the valuable and sensitive floodplain ecosystems. Surprisingly, plants did not belong to *C. lanceolata*, but could be identified as *C. grandiflora.* Therefore, the main goal of this study was to document the current spread and establishment of *C. grandiflora* in natural and semi-natural environments in southern Switzerland. In particular, by focusing on the situation in the Locarno region, we 1) investigated the geographical distribution of *C. grandiflora* in this region, 2) verified its taxonomical identity across sites, and 3) documented aspects of its biology and ecology (including a seed germination test). We also 4) compiled and discussed information on relevant aspects used for a rapid risk assessment of the invasive potential of alien species and, finally, 5) outlined management recommendations and options.

MATERIALS AND METHODS

To discriminate among *Coreopsis* species in the field, infer a practical identification key, and compile a morphological description of *C. grandiflora*, following taxonomical references were consulted: especially Flora of North America (Strother 2006) and Rothmaler - Exkursionsflora von Deutschland (Jäger et al. 2007), but also the protologue by Hogg (1826), Flora of Italy (Pignatti et al. 2017-2019), Dictionary of Gardening (Huxley et al. 1992), and The European Garden Flora (Cullen 2011). Synonyms were compiled by consulting the World Flora Online database (WFO 2022) and excluding taxa at the form rank. Although the North American *C. aurea* Aiton is cited in Pignatti et al. (2017-2019) as a casual alien in Italy, it was excluded here, because it is a basionym of *Bidens aurea* (Aiton) Sherff according to the Flora of North America (Strother & Weedon 2006).

Bidens and *Coreopsis* are often distinguished from each other by wingless cypselae that bear a pappus consisting of barbellate (rarely smooth) awns in *Bidens*, whereas cypselae are winged but lack a pappus in *Coreopsis* (e.g. Strother 2006). Recently, a morpho-anatomical study on traditional *Bidens* and *Coreopsis* species identified at least one feature that consistently separates the two genera: cypselae are striated in *Bidens* (due to the presence of translucent parenchyma cells along the long axis), whereas they lack such striation in *Coreopsis* (Tadesse & Crawford 2014). This study also found features characterizing well-supported clades of *Coreopsis*

species. For instance, the North American ones appear to form a well-supported clade (Crawford et al. 2009; Tadesse & Crawford 2014), and a monography of this group is currently underway (Mesfin Tadesse, personal communication).

To verify occurrence of the taxon in Canton Ticino, all known stations of *Coreopsis* inferred from unpublished reports by Giovanni Monotti and the data available in the national database of Info Flora (Info Flora 2021) were visited during Mai-July 2021. The study area ranged from Riazzino to Cavigliano (with particular attention to the floodplains of the Maggia River at Solduno) and the lower Maggia Valley (up to Lodano). New, previously unreported stands occurring in natural and semi-natural habitats were also recorded (but a detailed cartography was beyond the scope of this study). For each locality coordinates and abundance (counting unit: individuals or area in m^2) were collected with the application FlorApp v.2.8 (Info Flora 2016-2021) to be deposited in the national database of Info Flora. Particular attention was paid to taxonomy (*C. grandiflora* vs. *C. lanceolata* and hybrids), because according to Crawford et al. (2009), in Europe, the name *C. grandiflora* is often misapplied for large-headed *C. lanceolata* cultivar 'Grandiflora'. Voucher herbarium specimens were collected at selected sites and deposited at the herbarium of the Natural History Museum of Canton Ticino, LUG. In Canton Ticino, the climate is insubric: characterized by sunny and dry winters and sunny, but stormy, summers. The highest precipitation amounts fall in Spring (April-May) and early Fall (September-October), while the lowest are in Winter (MeteoSvizzera 2012). At the cantonal level, the average annual temperature in lowland areas (below 500 m a.s.l.) is 11.5 °C and the normal value of precipitation is 1842 mm per km^2 per year, but the spatial distribution is heterogeneous (Ufficio di statistica, 2021). At the Locarno-Monti measuring station (367 m a.s.l.), which is the most representative for the study area, the average annual temperature is 12.4 °C, in an average year there are 2171 hours of sunshine, the average annual precipitation is 1897 mm and the average annual relative humidity is 65 % (period 1981-2010; MeteoSvizzera 2012).

To have an idea of the alien range of distribution of the species in Europe, the following international and national online databases were consulted: Euro+Med Plantbase (Greuter 2006+), the Global Biodiversity Information Facility (GBIF 2022; visualizing presence data online of the accepted taxon '*Coreopsis grandiflora* Hogg ex Sw.' without downloading it) and the French National Inventory of Natural Heritage (MNHN & OFB 2003-2022; with the respective current taxonomic reference TAXREF 14.0). Finally, at the end of the study, we consulted all *Coreopsis* records of the Info Flora database (data extraction date 13.4.2022) to provide an approximate distribution of reported species, in particular *C. grandiflora*. This species was formally adopted by and added to the national database Info Flora at the beginning of April 2022 as *C. grandiflora* Sweet.

To document the species' biology and ecology, following aspects were recorded in the field during 2021: aspects of the reproductive biology (vegetative reproduction; phenology; insect visitation and pollination; seed set, viability and dispersal), habitat type and growth patterns in occupied areas (formation of dense or less dense monospecific stands), and regenerative capabilities (as reaction of plants to management practices, such as mowing). Seed viability was investigated with a simple (and preliminary) germination test for which 50 seeds were randomly selected from two individuals in each of two sites at the margins of the studied distribution (Cavigliano and Riazzino). Seeds were sown in a seedbed with conventional (organic) sowing soil. The seedbed was covered with a fine mesh mosquito net to exclude birds and granivorous arthropods. Seeds were watered twice, once at sowing time (26.6.2021) and a second time during the first week, while they were left afterwards at the mercy of local weather conditions (in Cavigliano). Seeds were checked every 2-3 days until germination, and every 2-3 weeks in the following months to report deaths or identify delayed germination.

To assess whether the species displays any invasive behavior or potential to become invasive its biological features, its spread potential and impact potential were analyzed by comparing them to the criteria listed in the catalogue of criteria by Info Flora (2014a) and used to compile the Black List and Watch List of invasive and potentially invasive alien species of Switzerland. In this catalogue, the criteria that allow estimation of the spread potential of a species in Switzerland consider: aspects of the sexual and vegetative reproduction (including number of seeds produced per plant, presence of a seed bank and reproduction via organs for clonal growth), any dispersal modes (both natural vectors and human activities), and the spread dynamic (especially speed) of the species in the alien range studied. The criteria that allow estimation of the impact potential examine three kinds of negative impacts: impacts on human and animal health, environmental impacts (i.e. on native species, in particular endangered species, and habitat structure), and economic impacts (i.e. damages to infrastructures, impacts on agriculture, etc.). A survey of other plant species present at *Coreopsis* stands was conducted on 28.5.2021 at the Maggia River floodplain site, in two plots of 10x10m and using FlorApp v.2.8 (Info Flora 2016-2021), to identify native species that could be affected by the alien species in this sensitive habitat. We did not quantify impact on native species, although discussed our qualitative estimation of growth patterns in occupied areas, i.e. formation of less dense or highly dense monospecific stands. To gather more information for the criteria, in addition to what documented by the study during fieldwork, the literature on *C. grandiflora* and *C. lanceolata* was searched in Google and Google Scholar, using the species name alone and also combined with 'weed', 'invasive' and 'noxious'.

We finally also report results of the removal action organized on 18.5.2022 (upon approval by the cantonal authorities) in which all *C. grandiflora* plants were removed via hand pulling from the river floodplain environments (see Marazzi & Gentilini 2022).

RESULTS AND DISCUSSION

Key to the species of *Coreopsis* wild in Switzerland, and their allies. (Figs. 1 and 2)

1a. Annuals; corolla of disc florets with 4 lobes (Fig. 1A). ..... *Coreopsis tinctoria.*

1b. Perennials; corolla of disc florets with 5 lobes (Fig. 1B). 2

2a. Aerial nodes proximal to first peduncle usually 1–3(–5), distalmost 1–3 internodes 1–2(–8) cm; cauline leaves disposed along the lower ¼ – ½ of the plant height (including flowering heads); basal and cauline leaves generally simple (undivided), rarely with 1-2 lateral lobes; flower heads up to ca 6 cm in diameter (except cv. 'Grandiflora'); cypselae 3-4 mm. ..... *Coreopsis lanceolata*

2b. Aerial nodes proximal to first peduncle usually (4–)6–10, distalmost 1–3 internodes 4–7 cm long; cauline leaves disposed along the lower ½ – $^{7}/_{8}$ of the plant height (including flowering heads); basal and cauline leaves usually 1(–2)-irregularly pinnately lobed with (3–)5–9 lobes, rarely simple; flower heads up to 10 cm in diameter; cypselae slightly smaller, 2-3 mm (Figs. 1C-D, 2). ..... *Coreopsis grandiflora*

Coreopsis grandiflora Hogg ex Sweet, The British Flower Garden, 2: pl. 175. 1826.

C. boykiniana Nutt., *C. grandiflora* var. *grandiflora* Hogg ex Sweet, *C. grandiflora* var. *harveyana* (A.Gray) Sherff, *C. grandiflora* var. *inclinata* J.R.Allison, *C. grandiflora* var. *longipes* (Hook.) Torr. & A.Gray, *C. grandiflora* var. *pilosa* Sherff, *C. grandiflora* var. *saxicola* (Alexander) E.B.Sm., *C. grandiflora* var. *subintegrifolia* Torr. & A.Gray, *C. harveyana* A.Gray, *C. heterolepis* Sherff, *C. heterophylla* Nutt., *C. longipes* Hook., *C. saxicola* Alexander, *C. saxicola* var. *duncanii* Sherff.

Specimina visa

Terre di Pedemonte, Cavigliano, along the cantonal road; 12.5.2021; E 2'699'220.16, N 1'115'753.37 ± 4 m; 294.9 m; LUG 20728-30 and LUG 20850-53. Terre di Pedemonte, Cavigliano, Alla Motta, along the railway; 12.5.2021; E 2'698'942.41, N 1'115'490.43 ± 2.5 m; 296.9 m; LUG 20716 and LUG 20723, and E 2'698'837.67, N 1'115'479.33 ± 9 m; 300.4 m; LUG 20724. Terre di Pedemonte, Cavigliano, in a garden, along the road and in a meadow; 12.5.2021; E 2'698'670.91, N 1'115'421.93 ± 4 m; 280.5 m; LUG 20725 and LUG 20818-20. Terre di Pedemonte, Cavigliano, along the railway; 12.5.2021; E 2'698'789.18, N 1'115'465.89 ± 16 m; 303.3 m; LUG 20726, LUG 20773, LUG 20794 and LUG 20845. Terre di Pedemonte, Tegna, along the railway; 12.5.2021; E 2'700'951.85, N 1'115'851.72 ± 6 m; 242.5 m; LUG 20731-32.

Gordola, floodplain of Verzasca river; 27.5.2021; E 2'709'675.24, N 1'115'173.58 ± 4 m; 206.3 m; LUG 20720 and LUG 20821. Gordola, along the road, 27.5.2021; E 2'709'361.09, N 1'115'603.98 ± 6 m; 245 m; LUG 20721-22.

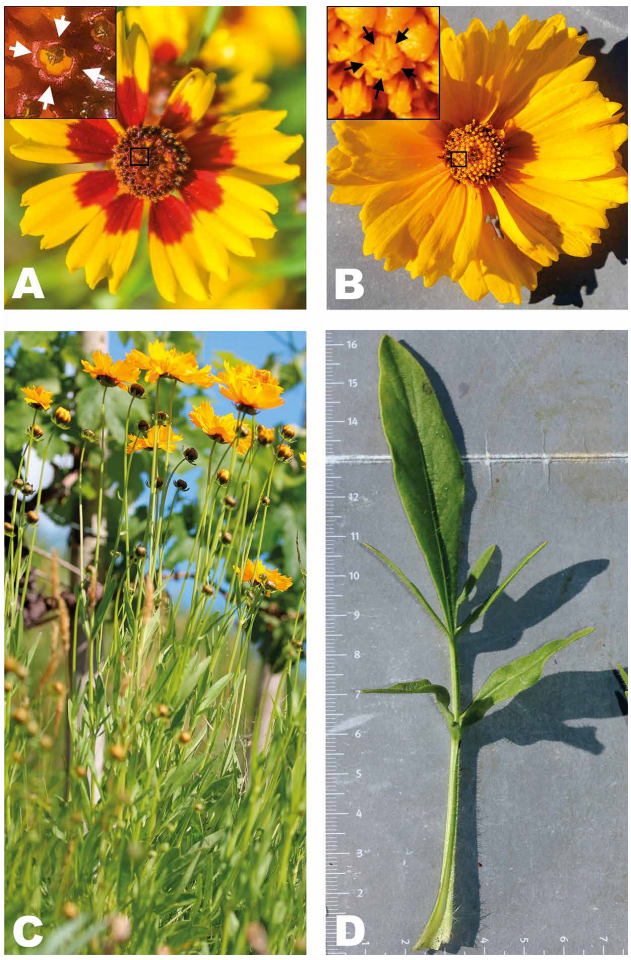

Figure 1: Selected diagnostic characters of wild *Coreopsis* species and allies in Switzerland. A: Ray flower with four corolla lobes (*C. tinctoria*; Photo: Krzysztof Golik, CC BY-SA 4.0). B-D: *C. grandiflora.* B: Ray flowers with five corolla lobes. C: Example of individuals with long internodes with cauline leaves until the upper half of the plant height (including flowering heads). D: Example of an irregularly pinnately lobed basal leaf.

Description

Perennials (rarely annuals), up to 60 cm, caespitose (Figs. 2A, B). Aerial nodes up to first peduncle 6-10, longest internodes 4-7(+) cm long. Stem leafy up to $^{7}/_{8}$ of its height. Leaves glabrous or hairy. Cauline leaves opposite, pinnate, bi-pinnate or pinnately lobate with (3-)5-9 lateral lobes, rarely simple (Figs. 1C, D). Terminal lobes narrowly lanceolate to linear or filiform, 15–45(–90+) × (0.5–)2–8(–12+) mm. Peduncle 8–20 cm long. Terminal heads up to 10 cm in diameter. Calyculi of lanceolate to linear bractlets. Phyllaries lance-ovate (Fig. 2C). Both ray (=ligulate) and disc florets yellow (Fig. 2D). Cypselae 2-3+ mm long, wings spreading, ± chartaceous (Fig. 2I). This species has a high variability in the number of ray flowers (Fig. 2D-G), probably resulting from horticultural selection (the cultivar 'Sunray', for example, has heads with a proliferation of ligulate flowers (Fig. 2F-G), a phenomenon similar to «double flowers» = *flore pleno*, where there is a multiplication of petals instead of reproductive organs). Flowering: late Spring-Summer (May-September).

Taxonomy

The polyphyly of *Bidens* nested within *Coreopsis* (see Introduction) prompted Banfi et al. (2018) to synonymize a few alien *Coreopsis* species with *Bidens* for the Euro+Med Flora. Hence, *C. grandiflora* became *Bidens sweetiana* Banfi, Galasso & Bartolucci (p. 54 in Banfi et al. 2018). Although other floras from European countries accepted this nomenclatural change abandoning genus *Coreopsis* (e.g., Galasso et al. 2018), we remained conservative in this study. Phylogenetic relationships among members of two genera appear indeed complex, but because some clades are consistently recognized with a strong support (e.g., the North American *Coreopsis* species; Crawford et al. 2009; Tadesse & Crawford 2014) and morphological features characterizing them are identified (e.g., Tadesse & Crawford 2014), other nomenclatural propositions that better reflects the morphological complexity in this group could be conceivable (see Tadesse & Crawford 2014; Mesfin Tadesse, personal communication).

Assigning a taxonomic identity to *Coreopsis* plants recorded in this study was often difficult, mainly because of the presence of cultivars and to less extent to that of apparent hybrids. Traits observed in individuals from almost all localities of the 14 studied municipalities were consistent with those described for *C. grandiflora*, and only one mainly with *C. lanceolata* (Tab. 1). While we observed a huge diversity of heads with yellow corollas (Fig. 2D-G), we found only a few individuals with red-brown dots (Fig. 2H) that could represent hy-

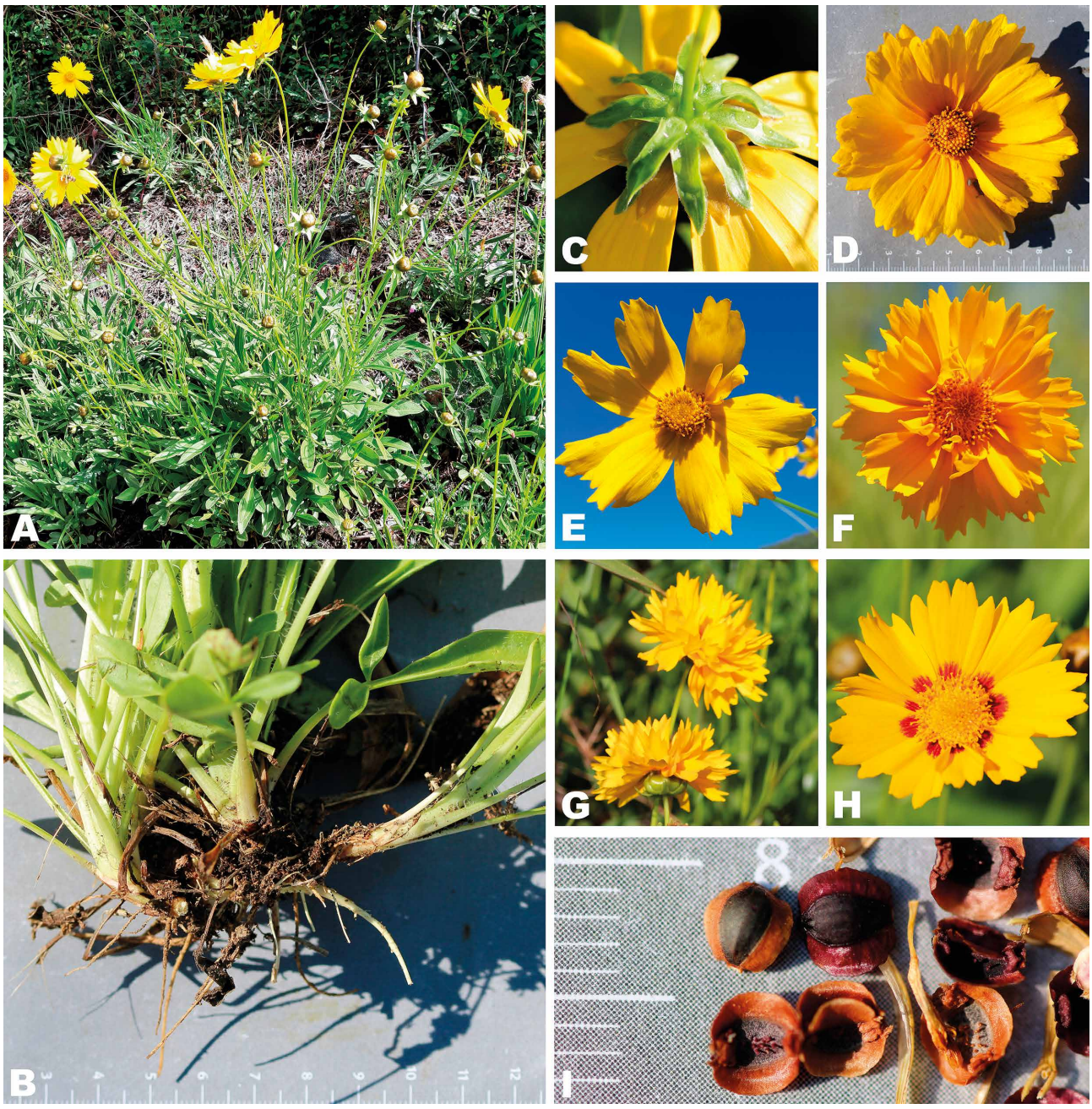

Figure 2: Morphology and biology of *Coreopsis grandiflora*. Images from individuals of the site in Cavigliano (Terre di Pedemonte, Switzerland), from early May (A-D) and early Summer 2020 (G-H). A: Habit. B: Vegetative reproduction by clonality, in which a plant (genet) consists of multiple ramets (three can be seen here). C: Calyculus, phyllaries (both green), sepals (yellowish), petals (yellow). D: Large yellow flower heads. E-G: Flower head variability. E: No proliferation. F-G: heads with a proliferation of ligulate flowers. H: Dotted ligulate flowers, possibly a sign of hybridization. I: Cypselae, with chartaceous wings.

Table 1: Geographic distribution (municipalities), origin of stands, and habitat category of reported sites of *Coreopsis* spp. in the study area in southern Switzerland. Accession numbers of floristic observations submitted to the National database Info Flora can be requested to authors or to Info Flora.

***Coreopsis* species**	**Municipality**	**Origin**	**Habitat categories**
C. grandiflora	Ascona	Cultivated	Gardens
	Avegno-Gordevio	Cultivated and established	Gardens and meadows
	Brione s/Minusio	Cultivated and subspontaneous	Gardens and meadows
	Cugnasco-Gerra	Cultivated and established	Gardens and meadows
	Gordola	Cultivated, subspontaneous, and established	Gardens, meadows, ruderal zones, and floodplains (Verzasca river)
	Lavertezzo (Riazzino)	Cultivated, subspontaneous, and established	Gardens, meadows, and ruderal zones
	Locarno	Cultivated, subspontaneous, and established	Gardens, meadows, ruderal zones, and floodplains (Maggia river)
	Losone	Subspontaneous	Meadows
	Maggia	Subspontaneous	Meadows
	Minusio	Cultivated, subspontaneous, and established	Gardens, meadows, and ruderal zones
	Orselina	Cultivated and established	Gardens and ruderal zones
	Tenero-Contra	Cultivated and subspontaneous	Gardens and meadows
	Terre di Pedemonte	Cultivated, subspontaneous, and established	Gardens, meadows, ruderal zones, and floodplains (Melezza river)
C. cf. *lanceolata*	Lavertezzo	Established	Meadows

bridization of *C. grandiflora* with *C. lanceolata*. Although the Michigan Flora Online also mentions that "some of the variability may represent hybridization with *C. lanceolata*" (Reznicek et al. 2011), we were unable to find any scientific publication about the two species hybridizing with each other. In addition, in a few sites some anomalous plants with traits more similar (or intermediate) to *C. lanceolata* were observed and likely explained as a sort of a "phenotypic artifact", resulting if *C. grandiflora* was cut at the beginning of the season that prompted an abnormal growth (e.g., Spring mowing of a lawn in Gordevio, maintenance of the roadside in Riazzino). This phenomenon is also observed with other Asteraceae commonly occurring in meadows, like *Crepis biennis* L. and *Erigeron annuus* (L.) Desf. (A. Gygax, personal observations). However, without being able to verify the habit growth under normal conditions, we cannot completely exclude that in these localities *C. lanceolata* occurs as well.

Alien range of distribution

In Europe, *C. grandiflora* appears to be confirmed as an established alien plant in a handful of countries like Belgium (Greuter 2006+) and Germany (Jäger et al. 2007), whereas it is considered cultivated or the introduction status is unknown in most other countries (Greuter 2006+). Presence occurrences recorded in GBIF actually suggest that the species could be more common than currently known; nevertheless, a detailed data analysis would be necessary to infer an accurate alien range of distribution of *C. grandiflora* in Europe.

In Switzerland, *C. grandiflora* is confirmed by our study as an established taxon in lowlands of the southern Alps. According to the Info Flora database, *C. grandiflora* has been reported only three times before this study, with two reports resulting from herbaria specimens of individuals collected in the wild in 1912 and 1919 at the same locality in northern Switzerland (Langendorf, Canton Solothurn) and a third report in 2004 from western Switzerland (Rivaz, Canton Vaud) in which the observer found it on rocky slopes at roadsides but was unsure of the identification. Most *Coreopsis* occurrences available in the Info Flora National database are attributed to *C. lanceolata* except for a handful submitted as *Coreopsis* sp. along with an image and attributed to *C. tinctoria* by the observers. Although it was not possible for us to verify all *C. lanceolata* reports, it is likely that at least few of them are in fact *C. grandiflora*, as was the case in southern Switzerland. In this study, *C. grandiflora* is spread as an escape across 13 of 14 municipalities of the Locarno region, including part of the Maggia Valley (Tab. 1; Fig. 3). We submitted a total of 141 floristic observations to the National database Info Flora. The largest stands were observed in Lavertezzo, Locarno and Terre di Pedemonte, with each of an estimated occupied area of ca. 100-250 m^2.

Biological and ecological aspects

Habitat ecology

In its native range of distribution, *C. grandiflora* grows in sandy soils of disturbed sites and ditches and in outcrops of granite and sandstone (Strother 2006). In its introduced range, the species is present along railroads and roadsides, in fields, sandy banks, meadows and clearings (Jäger et al. 2007; Reznicek et al. 2011). In

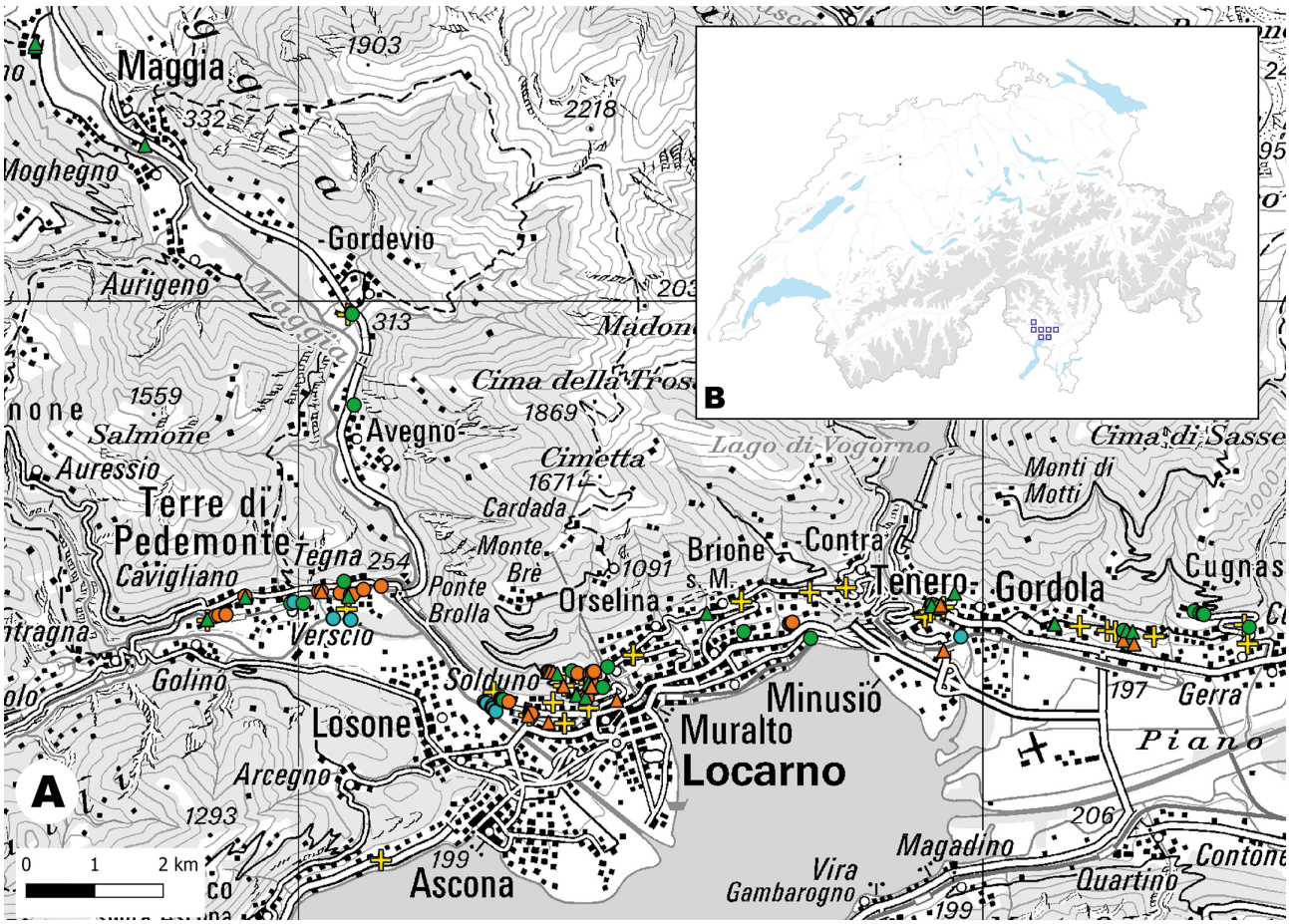

Figure 3: Geographic distribution of *Coreopsis grandiflora* in southern Switzerland. A: Reported sites of this study in the Locarno region. Legend: Population origin: circle = established, triangle = subspontaneous, and cross = cultivated. Habitat type: yellow = garden, green = meadow, orange = ruderal zone, and light blue = floodplain. Map source: © swisstopo. B: Distribution of floristic observations on the 5x5 km online national atlas map. Map source: © Info Flora 2.5.2022.

Canton Ticino, *C. grandiflora* grows in similar anthropogenic environments, especially in urban areas, like railroads, roadsides, meadows, vineyards or ruderal sites near gardens (Fig. 4). Escaped plants are most often found relatively near cultivated individuals. However, *C. grandiflora* has also been observed in natural floodplain areas of rivers (Melezza, Maggia, and Verzasca rivers; Tab. 1, Fig. 4C, E), where sites have sandy-stony river soils with arid to semi-arid thermophilic vegetation and are subject to occasional flooding. The climate in its native range (southeastern United States) is humid subtropical (also known as warm temperate climate) and it is characterized by hot and humid summers and cool to mild winters (Kottek et al. 2006).

Phenology and pollination

In the Locarno region the species flowers from May through September, with peak flowering in June-July. Pollination and sexual reproduction are functional and effective. Flowers appear to be highly attractive to insects, as multiple visitors were observed on heads at the same time and belonging to different taxonomic groups (Fig. 5): Hymenoptera (bees and bumblebees), Coleoptera (beetles), Lepidoptera (butterflies), and Diptera (flies and hoverflies). Preliminary observations suggest that bees and bumblebees are the most frequent pollinators. Some Coleoptera were using heads as mating sites (Fig. 5D).

Seed dispersal and germination

The first mature seeds were observed in June. Fruiting heads open to become cup-like while phyllaries dry out, exposing the cypselae inside that became loose and tend to fall out at any head movement, e.g. slight wind (Fig. 6A-D). Despite the small wings, seeds fall nearby the mother plants. Interestingly, we observed a range of seed sizes within a flower head (Fig. 6E), as was described for *C. lanceolata* as well (Banovetz & Scheiner 1994a): those in the center result smaller than those on the outside, because they mature after and get spatially constrained by the already developed seeds on the outside. The last fruiting heads mature late in Summer. Unless mowed or cut, plants remain green after setting seeds and throughout Winter (data not shown) and can thus be considered as hemicryptophytes.

The germination test showed that seeds are able to germinate in the same growing season in which they are produced and dispersed. The first seeds germinated about 40 days after sowing them towards the end of June (Fig. 6F-H). Seedlings survived until the end of August and then died due to lack of precipitation for over two weeks. Another set of seed germinated later in September and was still present in December. Curiously, Zeng et al. (2021) observed a similar pattern in China with naturalized *C. lanceolata*, in which no seedlings were found in the natural population in Summer, despite seeds have partial drought tolerance, but were

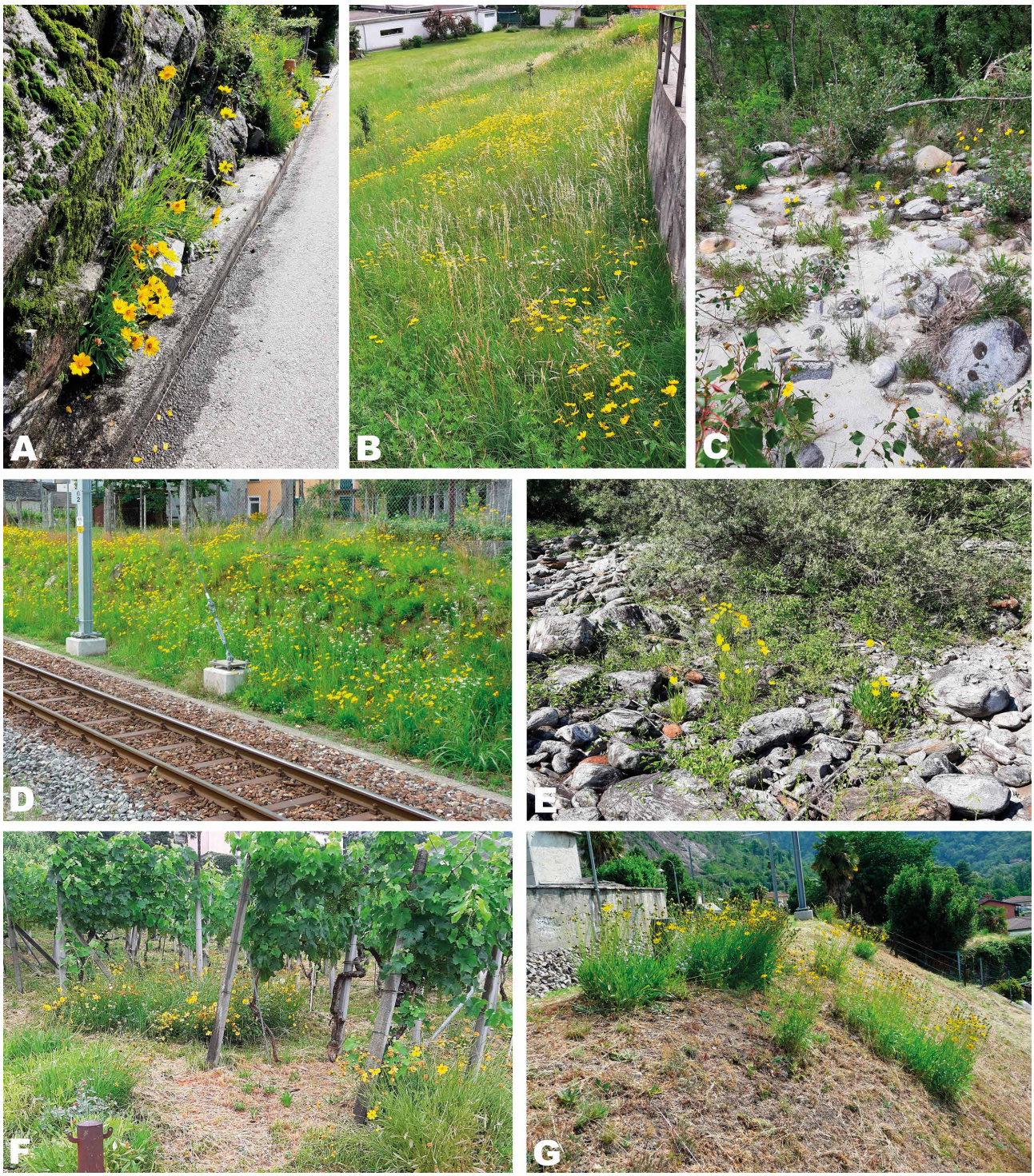

Figure 4: Examples of habitats and sites observed with *Coreopsis grandiflora* in southern Switzerland (Locarno region, Canton Ticino; Summer 2021). A: Roadsides (Cavigliano). B: Meadow (Tegna). C, E: Natural floodplain habitats. C: Floodplain of River Maggia (Solduno). D: Along railroads (Tegna). E: Floodplain of Verzasca River (Tenero). F: Vineyards with *C. grandiflora* plants spared from mowing (Gordola). G: Managed site with *C. grandiflora* plants spared from mowing (Tegna).

found from Fall to the next Spring. According to the authors, the species' long flowering time results in a continuous production of seeds that helps to avoid seasonal water shortage and increases seedling establishment during more favorable seasons.

Invasion potential

While in Central Europe *C. grandiflora* appears to be established in just a few countries, in China it is already listed as an invasive alien along with *C. lanceolata* and *C. tinctoria* (Xu et al. 2012; but, Zeng et al. 2021, cites the latter as non-invasive). In Australia, *C. lanceolata* was observed some 20 years ago to rapidly spread and become an environmental weed; yet, in some places the population seemed to accept it (Batianoff & Halford 2002). When dense stands of *C. grandiflora* are found in flower, forming impressive yellow patches in semi-natural habitats, it is understandable that the question raises as whether this species is or can become invasive and impact natural environments. We here discuss the spread potential and impact potential, consisting of features about reproduction (sexual, vegetative, and

seedbank), dispersal and recent geographic spread following the criteria catalogue of Info Flora (2014a) used for rapid risk assessments.

Reproduction and seed bank

Our observations in the field confirm that *C. grandiflora* is able to reproduce vegetatively by clonality (forming occasionally short rhizomes), but does not expand laterally via horizontal organs like stolons or long rhizomes (Fig. 2B). In fact, basal branches (ramets) start from the same root system and form small bushes (genets) that can reach 50-60 cm in diameter. However, some of the plants growing in Maggia River floodplains were rhizomatous, with up to 1 cm thick rhizomes, most likely as an adaptive response to the fact that they were flooded and buried by sand (Marazzi & Gentilini 2022). It is a short-lived perennial herbaceous species, but cutting may prolong their lifecycle. For instance, we observed (qualitatively) that bushes appear denser (with more stems) after they get cut or mowed above the point of growth of individual stems. This indicates that cutting stimulates regrowth similarly to herbivory events like cattle grazing. Clonality occurs also in *C. lanceolata* (also perennial) and seems to be a relevant factor enabling this species to spread in China where it is considered invasive, especially compared to *C. tinctoria* (annual) that lacks this vegetative reproduction mode and is actually considered non-invasive (Zeng et al. 2021).

Sexual reproduction is effective, as *C. grandiflora* manages to produce viable seeds, as confirmed by the germination test. One flower head produces from 30 to over 200 seeds, corresponding to an average of 120 seeds/head (Fig. 6E). A single bush can form dozens of floral heads and can thus produce thousands of seeds during the long flowering season, from May to September. Draught stress may actually affect germination of *C. grandiflora*, as was shown in *C. lanceolata* (Banovetz & Scheiner 1994b; Zeng et al. 2021) and *C. tinctoria* (Zeng et al. 2021). A high number of seeds combined with information on its ability to form or not form a persistent or a temporary seedbank provides an estimate of the contribution of sexual reproduction to the species' spread potential in the alien range (Info Flora 2014a).

A range of seed sizes within a flower head observed in *C. grandiflora* occurs also in *C. lanceolata*. In the latter, different seed sizes are related to different seed longevity and germination ability, with the smaller ones surviving up to two years and the larger ones up to 13 years, but the majority of total seeds (99%) still not surviving more than 10 years (Banovetz & Scheiner 1994a). The same authors also found that the species exhibits two types of dormancy in this closely related species (Banovetz & Scheiner 1994b). The germination peaks were highest after one year (resulting from the maturation process of seeds in the soil), but depended also on environmental conditions (temperature and drought in particular). Whether such patterns exist also in *C. grandiflora* needs to be investigated, but would mean that the species could form at least a temporary seedbank. These different strategies could allow the species to increase the probability of germination along the favorable period.

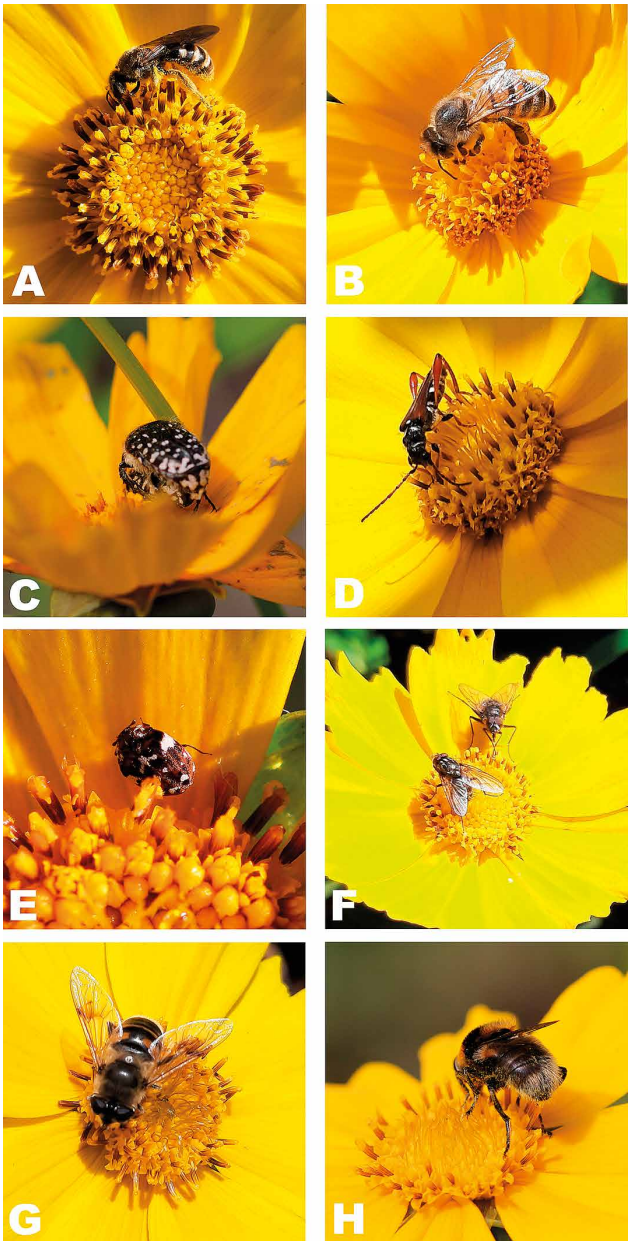

Figure 5: Examples of the diversity of insect floral visitors on *Coreopsis grandiflora* in the Locarno region (Switzerland). A-B: Hymenoptera. A: Halictidae, sweat bee, *Lasioglossum* sp. B: Apidae, European honey bee, *Apis mellifera*. C-E: Coleoptera. C: Scarabaeidae, white spotted rose beetles, *Oxythyrea funesta* (Poda von Neuhaus, 1761) using floral heads as mating sites. E: Cerambycidae, longhorn beetle, *Stenopterus rufus* (Linnaeus, 1767). F: Dermestidae, carpet beetle, *Anthrenus angustefasciatus* Ganglbauer, 1904. F-H: Diptera. F: Anthomyiidae sp. flies. G: Syrphidae droneflies, *Eristalis* sp. H: Syrphidae, bee-like hoverflies, *Merodon* sp.

Dispersal by natural vectors and humans

Seeds lack a pappus but are winged, with wings that do not exceed the surface of the seed itself (Fig. 2I), which is why they fly poorly and tend to fall in the immediate vicinity of the mother plant by gravity and to be dispersed further away probably by wind and water. In floodplain environments, river floods, although occasional, may actually represent an additional dispersal opportunity for the species, although the ability of seeds to float and maintain viability after immersion was not investigated in this study. We did not observe any noticeable animal

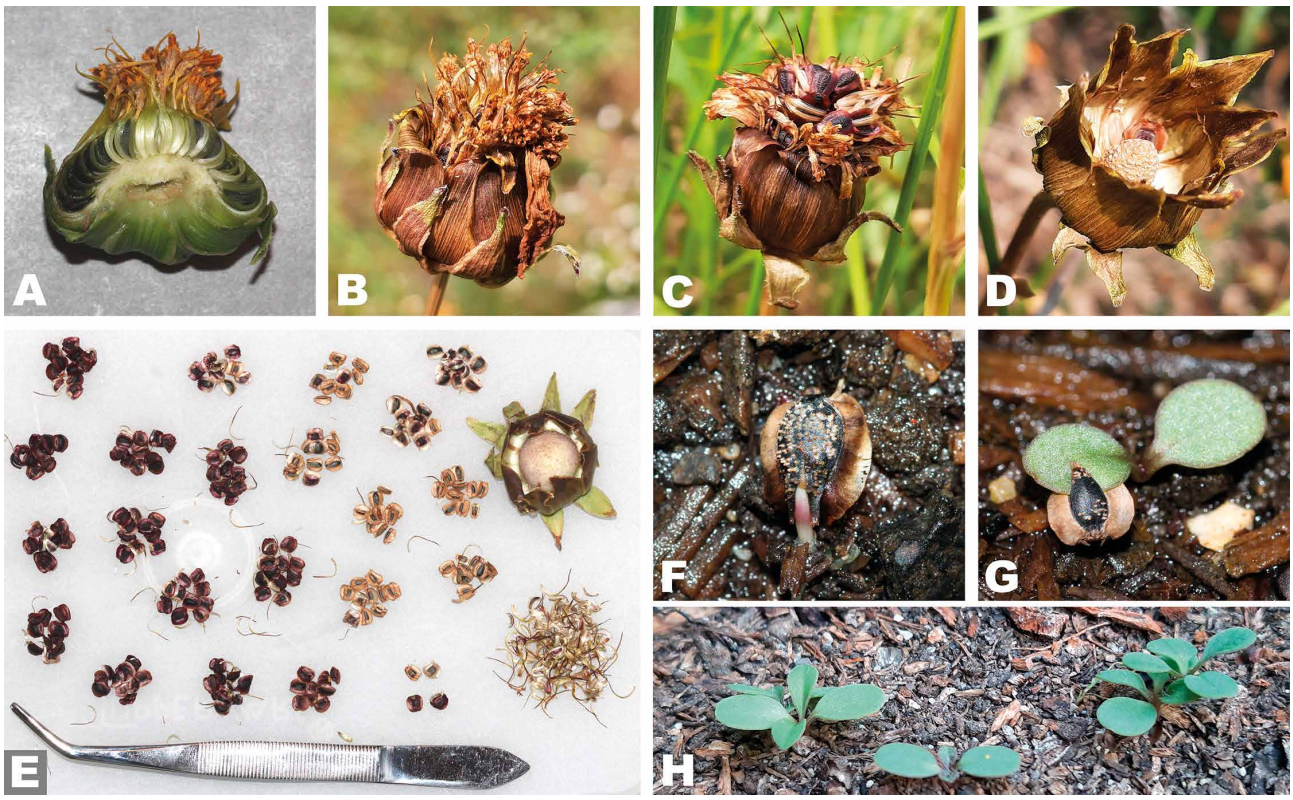

Figure 6: Fruiting heads, seed dispersal, and germination in *Coreopsis grandiflora* in southern Switzerland. A: Hand-made cross section across a head with maturing cypselae. B: Mature head (17.6.2021). C: Head with mature cypselae getting loose and ready for dispersal. D: Empty dried head. E: Cypselae tentatively ordered from the larger (darker color) to the smaller ones (lighter color), in groups of 10, and the sterile ones piled up below the empty head. F-H: Simple germination test. F: Germinating seed (5.8.2021). G: Seedling at the cotyledon stage, with the cypselae remain still attached (5.8.2021). H: Seedlings developing the first pair of leaves (29.8.2021).

feeding on or harvesting the seeds (no aril or elaiosome present) and, thus, consider animal-mediated dispersal as unlikely or playing a marginal role.

The widespread occurrence of individuals near gardens, along roads (Fig. 4A) and along the Vigezzina - Centovalli railway (in the Terre di Pedemonte area; Fig. 4D) suggest that the seeds are also effectively dispersed by air currents (turbulence) generated by road and rail traffic. In Terre di Pedemonte we suspect that all individuals along the railroad are derived from a single source population, in a garden at Cavigliano near both a road and the railroad. We also identified a number of human activities that favor the species in one way or the other, including: mowing of fruiting individuals left in place (increases seed dispersal), garden waste contaminated with seeds, movement of contaminated soil, etc. In addition, we noted that management practices at places with flowering *C. grandiflora* stands were influenced by the ornamental value of the plant; for instance, a meadow was moved all around the flowering *Coreopsis* plants, sparing them (Fig. 4F, G).

Environmental and other impacts

The discussion of the potential ecological impact of *C. grandiflora* considers the field observed growth pattern in the occupied areas (kind of environment, formation of dense or less dense monospecific populations). We did not observe dense and large monospecific populations of this species, with the exception of limited areas along the railroad (e.g., Cavigliano and Tegna). However, the species seems to be able to dominate especially where management practices seem to have contributed to reinforce the stands, to spread them further, and therefore to have accentuated (or caused) a situation of dominance. In Japan, vegetation cutting experiments with alien *C. lanceolata* showed that its abundance increased when cutting was performed once or not at all, but tended to decrease with higher frequencies with the collateral effect that this affected negatively the native vegetation (Saito & Okubo 2012).

Adaptation to ruderal, sandy, thermophilic environments cause *C. grandiflora* to be able to compete with native ruderal plants characteristic of these habitats. Floodplain environments of the Maggia River, include sandy and stony banks of high ecological value. Other alien species (a few of which invasive, Info Flora 2014b) occur at the site as well (Tab. 2), although as single scattered individuals. Fortunately, *C. grandiflora* does not form (yet) dense stands at this and other similar floodplain sites (Fig. 4C, E). Nevertheless, it still may compete for pollinators with native species present in this environment. Furthermore, by colonizing and increasing the covering of such sandy environments, *C. grandiflora* could stabilize these typically dynamic sites and affect the nesting in this kind of soils of solitary terricolous bees.

We could find information on impacts of *C. grandiflora* in its alien range of distribution only from a couple of studies from China. Hua et al. (2011) studied the species' impact on soil microbial communities at different altitudes. They found that its presence promoted the functional diversity of soil microbial communities,

and hypothesized that the species' apparently higher tolerance to poor soil conditions may be one important trait in allowing the invasion of habitats that were not suitable for the natives on the mountains. Indeed, Yanfang et al. (2012) showed that the species can apparently form a good symbiotic relationship with local arbuscular mycorrhizal fungi, which likely plays a role in conferring to the species the high tolerance to poor soil conditions. Although both studies write of *C. grandiflora* as an invasive, they do not mention that the species might be considered a 'transformer' (*sensu* Richardson et al. 2000). We found no studies quantitatively documenting negative impacts of *C. grandiflora* on the native community, despite the fact that it is listed as an invasive alien species in China (Xu et al. 2012). Regarding its closely related species, however, damages on biodiversity (more specifically on riparian endemic herbs) were highlighted for *C. lanceolata* in Japan (Saito & Okubo 2012). Information on other impacts, such as detrimental economic effects or impacts on human health, are also reported for *C. lanceolata* from Australia where, according to Batianoff & Harford (2002), the former include decreasing pasture productivity following the replacement of grasses and reduced crop growth after agricultural land is invaded, and the latter are associated with allergic reactions when densities of the plant are high. Further research to assess and quantify any direct impacts of *C. grandiflora* is therefore essential in and beyond southern Switzerland.

Rapid risk assessment

Based on what we observed in this exploratory study and the information we found in the literature, we consider the species to have a potentially invasive behavior. Despite the high number of seeds produced, we do not expect a high risk of invasiveness, because of the absence of significant vegetative reproduction, and its natural dispersal primarily over short distances and only occasionally over long distances. Moreover, the species' occurrence is exacerbated by a range of management practices and other human activities that contribute to its spread and make it difficult to assess the natural spread dynamic and behavior of the species in the absence of all these practices. Finally, its presence in warmer areas of grasslands and vineyards, such as roadside verges and stone walls, suggests that it may also enter dry, thermophilic meadows and pastures in the future.

In sum, these considerations highlight the need for further detailed research into the invasive potential of *C. grandiflora*. This includes, on one hand, gathering more detailed information on its ecology and reproductive biology, particularly its pollination and dispersal mode and colonization success (germination rate, survival/mortality rate, seed bank formation, etc.) and life cycle under undisturbed conditions. On the other hand, impacts on natural and semi-natural environments need to be investigated, and it is important to understand, if the species can achieve "on her own" the density of stands observed in urban and semi-natural environments, where management practices and other human activities promote the plant. Completely unaddressed and unknown is any aspect about the genetics, given that multiple introductions as an ornamental may have led to a high genetic diversity within the species in its alien range (as was described in northern China; Liang et al. 2008) that may have played a role in its establishment and spread dynamic.

Table 2: Floristic survey at two 10x10m plots with *C. grandiflora* (floodplain of the Maggia River, Solduno, Switzerland; 27.5.2021). Plot 1: Info Flora ID 2921894; E 2'702'854.92, N 1'114'126.29. Plot 2: Info Flora ID 2921893; E 2'702'750.78, N 1'114'221.69. *: alien species, **: invasive alien species of the Black List (Info Flora 2014b).

Plot	Genus	Species	Authority
1+2	*Anthyllis*	*vulneraria*	L.
1+2	*Artemisia*	*campestris*	L.
1+2	*Bromus*	*erectus*	Huds.
1+2	*Centaurea*	*scabiosa*	L.
1+2	*Cytisus*	*scoparius*	(L.) Link
1+2	*Echium*	*vulgare*	L.
1+2	*Euphorbia*	*cyparissias*	L.
1+2	*Lotus*	*corniculatus*	L.
1+2	*Populus*	*nigra*	aggr.
1+2	*Rumex*	*acetosella*	L.
1	*Buddleja*	*davidii***	Franch.
1	*Calamagrostis*	sp.	
1	*Centaurea*	*scabiosa*	L.
1	*Pyracantha*	*coccinea**	M.Roem.
1	*Salix*	*elaeagnos*	Scop.
1	*Solidago*	*gigantea***	Aiton
2	*Ailanthus*	*altissima***	(Mill.) Swingle
2	*Albizia*	*julibrissin**	Durazz.
2	*Cotoneaster*	*horizontalis**	Decne.
2	*Festuca*	sp.	
2	*Hieracium*	*piloselloides*	Vill.
2	*Hippocrepis*	*comosa*	L.
2	*Robinia*	*pseudoacacia***	L.
2	*Sanguisorba*	*minor*	Scop.
2	*Thymus*	*serpyllum*	aggr.

Management recommendations

Early detection and prevention

The currently still limited presence of *C. grandiflora* in natural environments in southern Switzerland should prompt precautionary action to avoid further spread and undesired negative impacts of this alien in valuable environments. Therefore, we recommend active preventive management of this species in (semi-)natural sites (starting with the floodplains of the Maggia River at Solduno and cultivated individuals in nearby populated areas), with the goal of containing its further spread and possibly removing it from these environments. In the urban context, aware of the appreciation for *C. grandiflora* as an ornamental plant, we suggest to at least adjust management practices so that a spread of the plant towards sensitive environments can be

avoided. Awareness raising of the population could certainly help, especially in municipalities where the species is widespread in gardens. Hence, communication and coordination with the authorities responsible for the management of roadsides (roads and railways) is essential to avoid the plant being favored for its ornamental appearance. Ideally, trade of *C. grandiflora* and its cultivars should be stopped (i.e. prohibited), so that this is no longer a source of new introductions.

Control

For control, we recommend manual eradication (hand pulling) in the case of few individuals and small populations and a mowing/cutting strategy in the case of larger dense populations. Hand pulling is easy and effective, and the only option we recommend in sensitive environments, such as river floodplains. For instance, removal of *C. grandiflora* from the Maggia River in Solduno (ca. 250 plants in total) was achieved by two per-

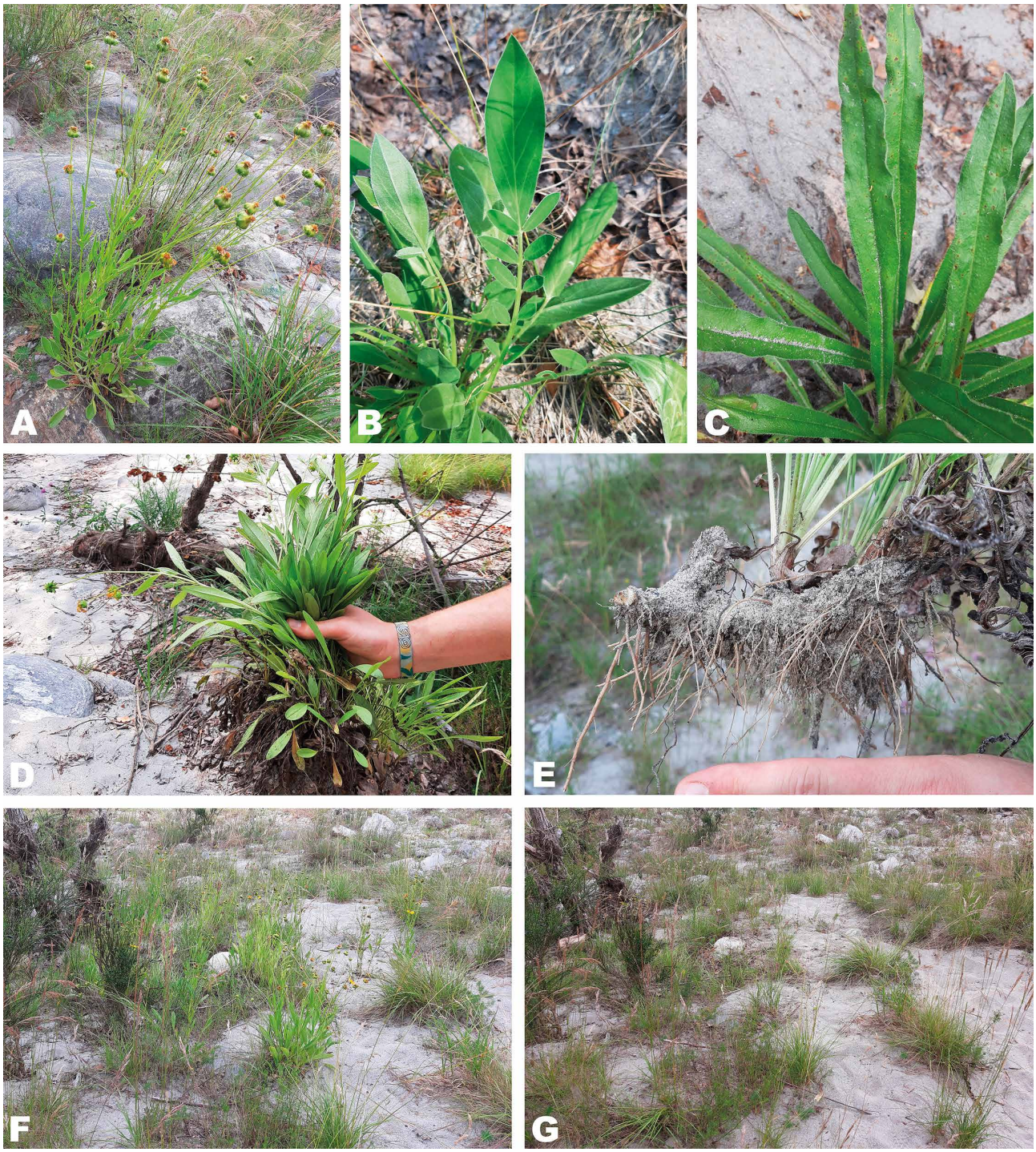

Figure 7: Removal of *Coreopsis grandiflora* from the floodplains Maggia River in Solduno (southern Switzerland) through hand pulling (15.6.2022; see report by Marazzi & Gentilini 2022). A: Removal should occur at the latest when the fruiting heads are still green and closed. B-C: Examples of native plant species that can be confused with *C. grandiflora* when sterile. B: *Anthyllis vulneraria* (Fabaceae). C, *Echium vulgare* (Boraginaceae). D-E: Examples of pulled individuals of *C. grandiflora*. D: Cluster of single individuals, possibly from a clump of seeds that germinated at the same time). E: Individuals (ramets) connected by a rhizome that was flooded and buried by sand. F-G: Example of a treated area of the river floodplain. F: Before removal action. G: Right after *C. grandiflora* plants have been removed.

sons in one morning (Marazzi & Gentilini 2022; Fig. 7), and the following aspects should be considered. Ideally, removal by hand pulling should occur during the flowering peak (plants can be easily spotted), but at the latest when the fruiting heads are still green and closed (Fig. 7A). When they are ripe and open, chances are high to favor seed dispersal and thus be counterproductive. Plants should be pulled slowly so as to unearth as much of the root system as possible, as the plant can be rhizomatous, particularly in active floodplain environments where plants can be buried by river flooding (Fig. 7D-E). Non-flowering or sterile plants of *C. grandiflora* should also be removed, but because of the risk to confuse them with native plant species that have similar non-flowering habit (for example, *Anthyllis vulneraria* [Fig. 7B], *Centaurea scabiosa*, *Echium vulgare* [Fig. 7C], *Solidago virgaurea*), the intervention team should be accompanied or trained by a botanical expert that can ensure correct identification of sterile individuals. The site should be checked again in the following year(s) to remove any individual that was overseen.

Cutting appears to be a more difficult control option than pulling. Although simpler to carry out in meadows than hand pulling, there seems to be no magic number of cuttings in the case of *C. lanceolata*, but a single cutting should be avoided, as it increases the alien's density (see Saito & Okubo 2012). Such cutting strategy should also consider the fact that repeated cutting could also affect any native species still occurring at the managed site. If possible, cuttings should be done at ground level in order to cut plants below the ramets' growing point. The first should be at the beginning of the season (around March) or before the first flower heads start turning into fruits (in May), given that seeds are readily formed (from the end of May onwards). A second and more cuttings should be done when re-sprouting ramets are well developed again (about 20 cm tall). This means that it is necessary to check for re-sprouting of the plants in the following weeks and repeat cutting if necessary or eradicate the plants manually. If a seed bank may have formed in the soil, it might be worth to check the site for seedlings over a longer period. The cut material can be left to dry in place if cutting is done before flowering, because it should not be able to root. However, if cutting occurs during or after flowering, we recommend disposing of the material with the house waste and not in the compost.

Monitoring

Monitoring of the species should occur at both the local scale of a treated site and the regional scale of the species' occurrence. Monitoring of treated sites (i.e. where the species has been eradicated) is important to prevent new invasion at these sites, especially if the propagule pressure from surrounding sources still persists and new introductions are thus likely (for example, seeds dispersed from *C. grandiflora* plants in nearby gardens). For instance, management strategies should identify such sources and consider additional control options to diminish or even zero the propagule pressure. At a larger geographic scale, it means to monitor *C. grandiflora*'s occurrence and spread in southern Switzerland, in order to detect any acceleration of its spread and/or expansion to new regions of the country. As a thermophile species it is likely to benefit from global warming, in particular from milder winters and extreme summer temperatures. These adaptive responses need to be studied along with the species' environmental impacts.

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