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High proportion of cactus species threatened with extinction

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A high proportion of plant species is predicted to be threatened with extinction in the near future. However, the threat status of only a small number has been evaluated compared with key animal groups, rendering the magnitude and nature of the risks plants face unclear. Here we report the results of a global species assessment for the largest plant taxon evaluated to date under the International Union for Conservation of Nature (IUCN) Red List Categories and Criteria, the iconic Cactaceae (cacti). We show that cacti are among the most threatened taxonomic groups assessed to date, with 31% of the 1,478 evaluated species threatened, demonstrating the high anthropogenic pressures on biodiversity in arid lands. The distribution of threatened species and the predominant threatening processes and drivers are different to those described for other taxa. The most significant threat processes comprise land conversion to agriculture and aquaculture, collection as biological resources, and residential and commercial development. The dominant drivers of extinction risk are the unscrupulous collection of live plants and seeds for horticultural trade and private ornamental collections, smallholder livestock ranching and smallholder annual agriculture. Our findings demonstrate that global species assessments are readily achievable for major groups of plants with relatively moderate resources, and highlight different conservation priorities and actions to those derived from species assessments of key animal groups.

Plants are of fundamental importance to much of the rest of biodiversity and to many ecosystem functions, processes and services. However, the global status of plant species, that is their likelihood of extinction in the near future, remains poorly understood. Only 19,374 (6%) of an estimated ~300,000 species[1] have been evaluated against the current IUCN Red List Criteria[2]. Moreover, global species assessments, in which the extinction risk of every extant species in a taxonomic group is systematically assessed, have been conducted only for very few plant groups (such as cycads, conifers, mangroves, sea grasses[3–5]) of which most are not especially diverse.

This situation is troublesome because there is evidence suggesting that the conservation status of plant species is of particular concern. Despite the small proportion of plants whose threat status has been evaluated, they nonetheless constitute a high proportion (47%) of all threatened species (across all kingdoms) currently on the IUCN Red List[5]. In addition, plant species are known to have geographic range sizes, a key correlate of extinction risk, that are on average smaller than those of many other groups; the smallest ranges are typically also much smaller than their equivalents among vertebrate groups[6]. Estimates of likely levels of recent and future plant extinction also indicate that these may be high[7,8].

Responding to this concern, determining the threat status of all known plant species, as far as is possible, has been identified as a key target for the Global Strategy for Plant Conservation 2011–2020 (ref. 9). This follows the global failure to meet the previous incarnation of this target as of 2010 (ref. 10). It is difficult to determine why, in contrast to vertebrates[5,11,12], progress has been so slow, and comprehensive assessments of plant groups are so scarce. Likely reasons include the assumption that there is insufficient information available to assess most plant species against the IUCN Red List Criteria, including data on species' geographic distributions (although much valuable distributional data undoubtedly reside, unsynthesized, in herbaria and botanical collections). In addition, plants lack the popular appeal of some animal groups, making it difficult to attract the funding to support global species assessments. And the costs of such assessments are thought to be restrictively high[13–18].

Here we challenge these assumptions, presenting the results of the largest comprehensive assessment to date of an entire plant taxon, the cacti, against the IUCN Red List Categories and Criteria (1,480 extant species of which 1,478 were evaluated, with two species for which no information could be obtained). We focus on the levels of threat to species, how species at different levels of threat are distributed, the nature of the threats and the practicality of such global species assessments for plants. The cacti are a culturally significant group, perceived as amongst the more charismatic of plant taxa. This has led to a long history of human use, including for private and public ornamental plant collections, leading to major conservation concerns. Surprisingly, only 11% of cactus species had been evaluated for the Red List before 2013. Cacti are distributed predominantly in, and are somewhat emblematic of, New World arid lands (only one species naturally occurs in Africa and Asia; Supplementary Table 1). Despite huge anthropogenic pressures, these regions have not attracted the conservation attention associated with other biomes, particularly tropical forests[19,20].

Levels of threat

Using the IUCN Red List Categories and Criteria, we found that cacti are the fifth most threatened[5] of any major taxonomic group to be completely assessed to date, with 31% of species threatened. The only groups to contain a higher proportion of threatened species are cycads (63% threatened species[5]), amphibians (41%[5,11]), corals (33%[5,21]) and conifers (34%[5]). Therefore, three of the five most threatened groups assessed to date are plants. By comparison, 25% of mammal species[5,12] and 13% of bird species are threatened[5]. Among the cacti, 99 (6.7%) species are classified as Critically Endangered, 177 (12%) as Endangered and 140 (9.4%) as Vulnerable (Supplementary Table 2).

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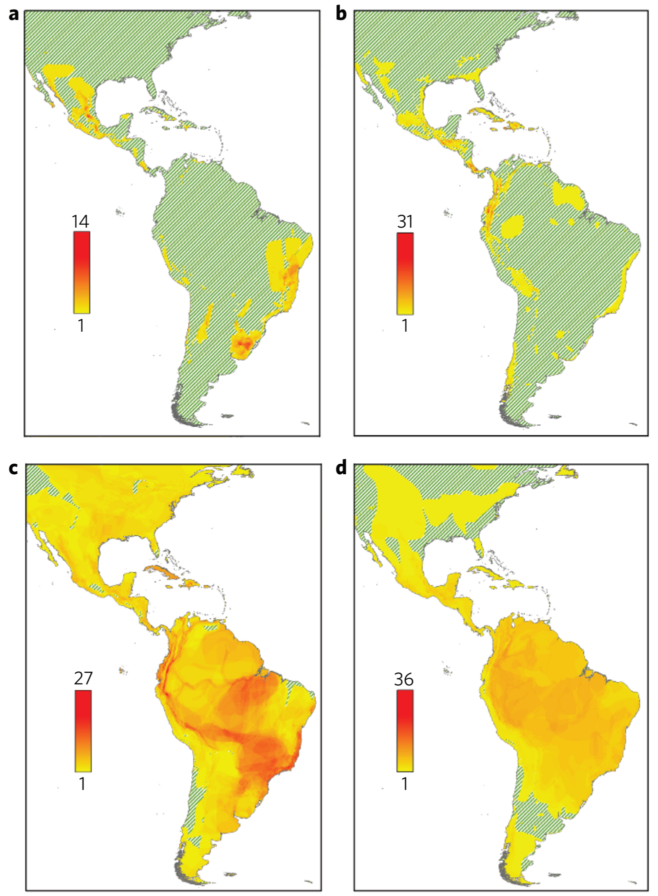

Figure 1 | Geographic distribution of threatened species. a–d, Number of threatened species (IUCN Red List Categories Vulnerable, Endangered and Critically Endangered) of cacti (**a**), amphibians (**b**), birds (**c**) and mammals (**d**) (see Methods).

Hotspots of threat

The hotspots of threatened cactus species overlap little, if at all, with those that have been highlighted for other taxonomic groups and that consequently have driven much thinking about the role of such areas in conservation planning (Fig. 1). Whereas hotspots of threatened cacti are inevitably found in arid regions, those of threatened species of amphibians, birds and mammals tend to be found in more mesic habitats. The peak of threatened cactus species richness is found in a highly restricted area in southern Rio Grande do Sul, Brazil, and northern Artigas, Uruguay (area ~500 km^2; Fig. 1a). This region also shows a peak in the proportion of species threatened with extinction (Fig. 2a). Other hotspots of threatened cacti are found in the states of Querétaro and San Luis Potosí, and in Oaxaca and Puebla in the Tehuacán-Cuicatlán region, Mexico; in Brazil in eastern Bahia and northern Minas Gerais; in Chile in the southern portion of Antofagasta; and in eastern Uruguay (Fig. 1a). The narrowness of the peaks of threatened species richness of cacti reflects their particularly small geographic range sizes (first quartile <1,332 km^2, median range size of threatened species is 1,529 km^2). Other areas with a low overall richness but a high proportion of threatened species occur in Guatemala, Colombia and several parts of Peru and Chile (Fig. 2a). The main centres of cactus diversity are found in the Chihuahuan Desert and in the Tehuacán-Cuicatlán region, in northern and central Mexico respectively, and in southern Bolivia and eastern Brazil (Fig. 2a; ref. 22). Some of these species-rich areas coincide with hotspots of threatened cactus species (Fig. 1a).

Threats

Cacti experience a diverse range of threats, the predominant processes (that is the direct human activities responsible for the degradation, destruction and/or impairment of biodiversity[23]) being land conversion to agriculture and aquaculture, collection as biological resources, and residential and commercial development (Figs 3a and 4a). Agriculture is the most widespread threat to cacti, affecting species in large parts of northern Mexico, Mesoamerica and the southern portion of South America (Fig. 3a). Cacti in coastal areas, such as the Baja California peninsula in Mexico and the Caribbean, are mainly affected by residential and commercial development. The latter threat, in conjunction with agriculture, affects cacti along the Pacific coast of Mexico and the central coast of Brazil. Collecting cacti for biological resources (for instance for ornamental collections and wood) is the main threat process affecting species distributed along the Peruvian and Chilean coasts. Unsurprisingly, areas where all three threat processes act together are often regions harbouring the highest concentrations of threatened species, such as central Mexico and eastern Brazil (Fig. 3a).

The most important proximate drivers of extinction risk, that is the ultimate factors contributing to or enabling the threat process[23] among threatened cacti, are unscrupulous collection of live plants and seeds for the horticultural trade and for private ornamental collections (affecting 47% of threatened cacti), smallholder livestock ranching (31%) and smallholder annual agriculture (24%; Fig. 4b). In eastern and southern Brazil, the two main drivers of land use change are smallholder ranching and smallholder agriculture, affecting 61 and 46 species, respectively (Fig. 3b,e). However, an additional driver of land use change in southern Brazil is agro-industrial plantations of *Eucalyptus* (Fig. 3c); land conversion for plantations affects at least 27 species, including the Endangered *Parodia muricata*, but also the leaf litter from these trees shades cacti, preventing them from being pollinated and from flowering, and often kills adult specimens. In eastern Brazil, the situation is exacerbated by a relatively high number of species (15 in Bahia and 19 in Minas Gerais) that are affected by quarrying, the fifth most frequent threat driver for threatened cacti (Fig. 4b). Edaphic specificity is common among these plants[24] and a large number of Brazilian species, such as *Arthrocereus glaziovii* and *Coleocephalocereus purpureus*, only grow on iron-rich canga or on inselbergs, both of which are sought after by the mining industry. An extreme case is that of *Arrojadoa marylaniae*, which may become extinct in the near future, for the single white quartz rock on which it is exclusively found is threatened by mining. In north-central Mexico the two main drivers of land use change are the same as in Brazil, with nomadic grazing as an additional driver of land use change in this region (Fig. 3b,d,e). In the north-western part of Mexico, species such as *Mammillaria bocensis* and *Corynopuntia reflexispina* are unexpectedly becoming threatened by aquaculture, as shrimp farming expands into the desert.

Cactaceae are a key component of the arid floras of the New World. They are probably more susceptible to collection activities than other groups of plants that are characteristic of these environments. However, until similar assessments are completed for such other groups it is hard to speculate on how the threats will differ, especially for plants with more ephemeral life cycles.

Human use

Unlike most other groups that have been completely globally assessed to date, more than a half of all cactus species (57%) are used by people. The most common use is for ornamental horticulture (674 species), which in most cases is related to gathering plants and seeds for specialized collections. People also use cacti as food for human consumption (154 species) and medicine (both human and veterinary; 64 species; Fig. 4c). Among the threatened cacti species,

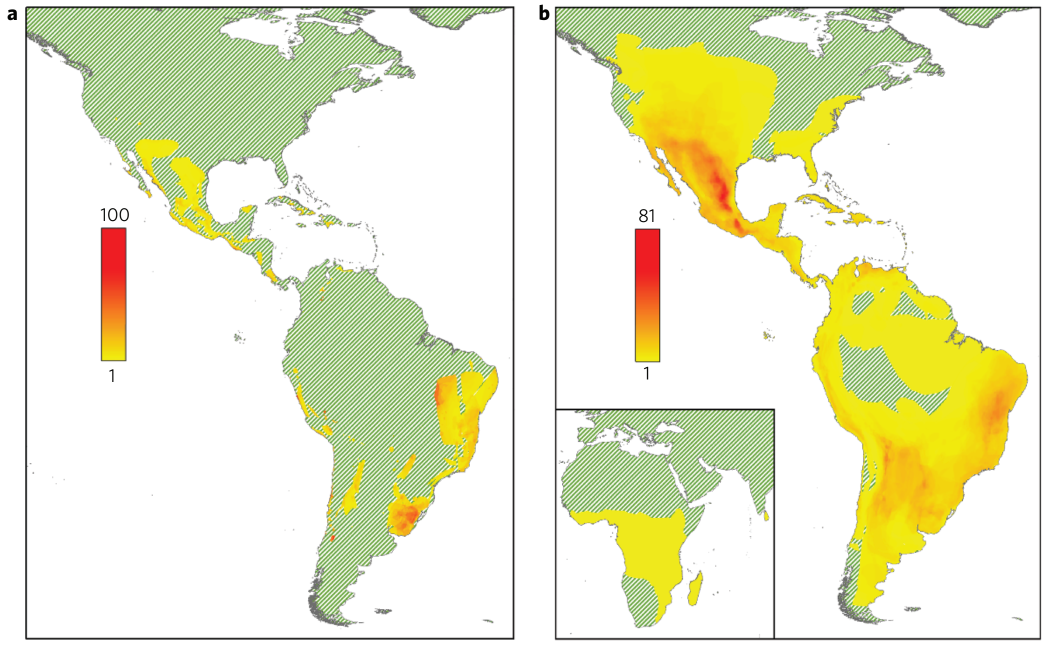

Figure 2 | Patterns of biodiversity of Cactaceae. a, Proportion of species that are threatened (Vulnerable, Endangered and Critically Endangered). **b**, Total species richness.

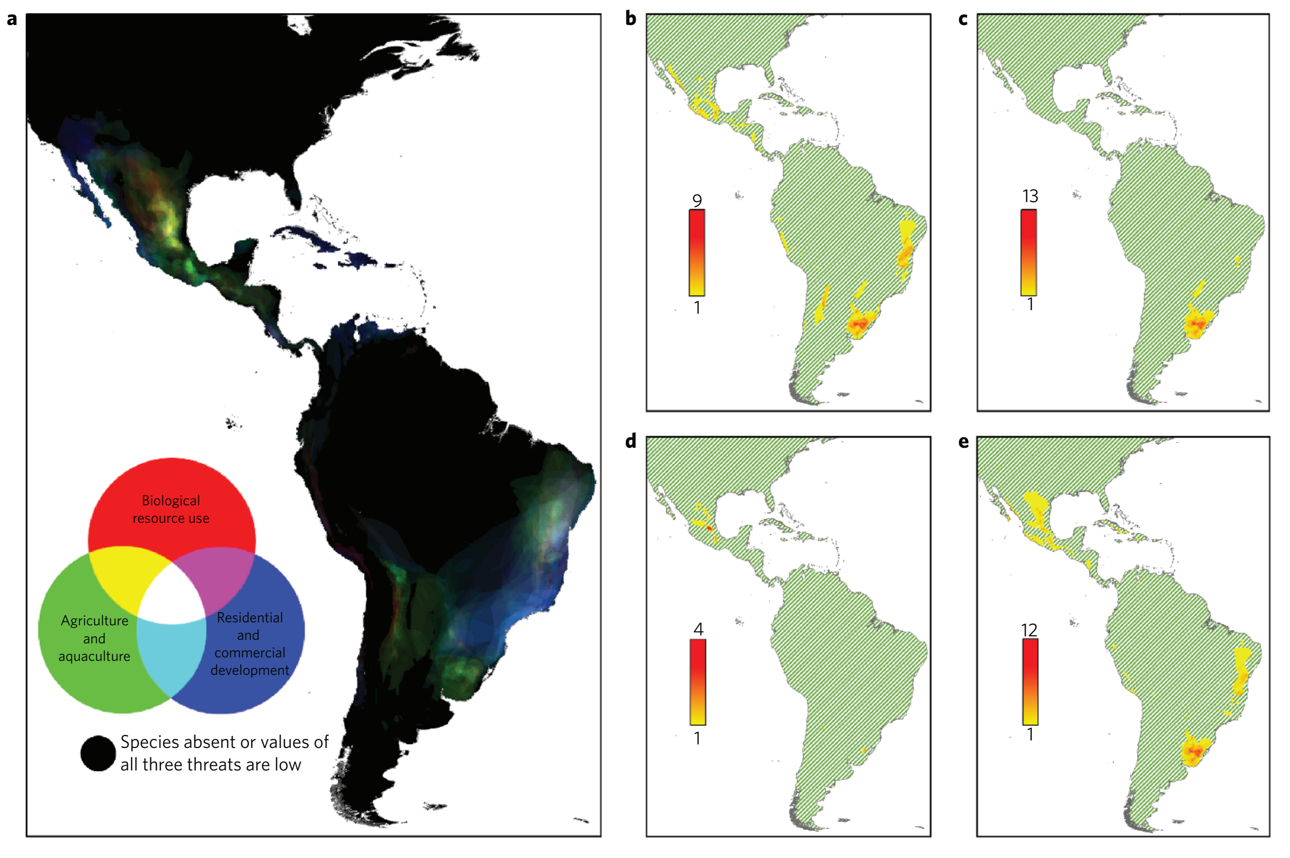

Figure 3 | Threatening processes and drivers impacting cacti. a, Geographical distribution of the three most common threat processes. Green, agriculture/aquaculture; red, overexploitation; and blue, residential/commercial development. These colours change as the threats combine, turning white when all three threats are present in an area. The brighter the colour, the higher the number of species affected by that particular threat. Black corresponds to those areas where all three threat values are low. **b–e**, Geographic distribution of threat drivers: smallholder ranching (**b**), wood agroindustry plantations (**c**), nomadic grazing (**d**) and annual smallholder farming (non-timber crops) (**e**).

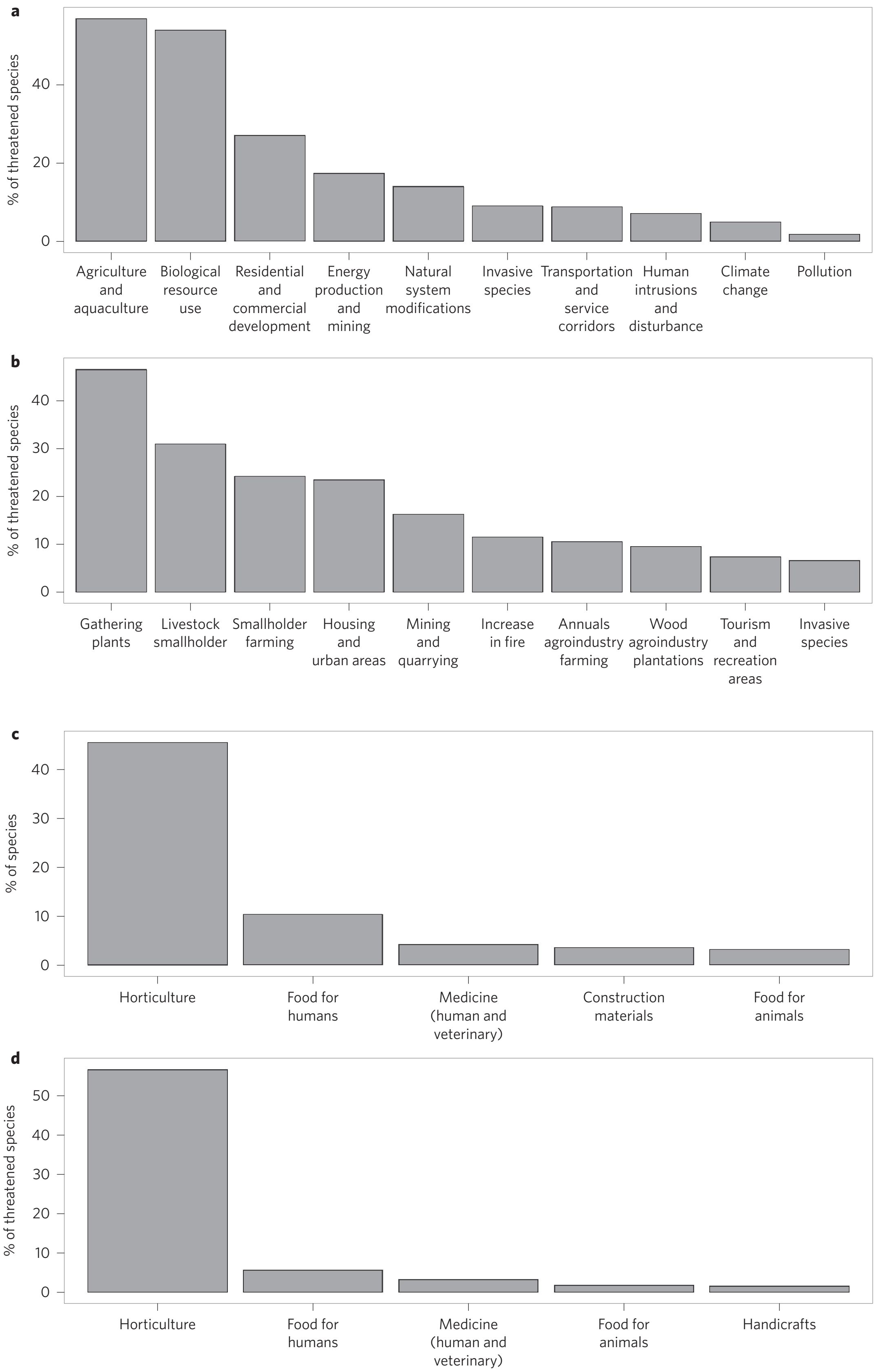

Figure 4 | Cactus species affected by different threat processes and drivers, and used for different purposes. a, Percentage of threatened cactus species threatened by different processes. **b**, Percentage of threatened cactus species experiencing different proximate threat drivers. **c**, Percentage of cactus species used for different purposes. **d**, Percentage of threatened cactus species used for different purposes. Only the main threats and uses are shown; for complete lists of threat processes, threat drivers and uses see Supplementary Tables 3–6.

64% are utilized by humans in some form and 57% (236 species) are used in horticulture (Fig. 4d). Ever since Europeans first discovered cacti, they have been regarded as precious collectable objects sought by collectors for their unique appearance, unpredictably beautiful flowers and their rarity in terms of the narrowness of their geographic ranges. Large cacti are sought after as major exhibition pieces, but smaller ones are more readily discreetly collected. A general linear model identified significant differences in height between threat categories, between cacti that are utilized and those which are not, and with mean elevation, although the explanatory power of the final model was low ($R^2 = 0.106$); whether the species was in a protected area or not was also retained in the model but was not significant (full details Supplementary Information Tables 7 and 8). Height was different between threat categories ($F_{[4,693]} = 8.29$, $P < 0.0001$) with Least Concern and Near Threatened species being significantly taller than Critically Endangered ones (difference in mean Least Concern (mean = 2.51 m, s.e. = 0.154 m, $n = 475$) and Critically Endangered (mean = 1.27 m, s.e. = 0.41 m, $n = 41$) 1.241 m; Near Threatened (mean = 4.59 m, s.e. = 2.4 m, $n = 41$) and Critically Endangered difference in mean 3.32 m). Cacti which are utilized were significantly smaller than those which are not ($F_{[2,693]} = 17.94$, $P < 0.0001$), and there was a significant inverse relationship between cactus height and mean elevation ($F_{[1,693]} = 15.07$, $P < 0.001$).

A cumulative link model exploring factors affecting the IUCN threat category of each species also had low explanatory power (pseudo $R^2 = 0.104$). It did, however, identify significant differences in threat category between species found in protected areas compared with those which were unprotected (likelihood ratio statistic = 19.37, $P < 0.001$ see Supplementary Table 9 for full model results). The proportion of Least Concern species was much greater in protected areas, and unprotected areas had greater proportions of Vulnerable, Endangered and Critically Endangered species. The model also highlighted height ($z = 1.98$, $P = 0.047$) and upper elevation ($z = 1.9$, $P = 0.057$) as having marginally significant effects on threat category.

Trade in cactus species takes place at both national and international levels, and it is often illegal[25]. We found that 86% of threatened cacti used in horticulture are extracted from wild populations. Illegal trade has been reduced to a certain extent by the inclusion, since 1975, of the whole family (with a few exemptions) in the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) and by the availability of plants grown from seed in international markets. However, the threat of collection prevails, especially in those countries where the implementation of CITES has only recently been enforced, such as in Peru, where the proportion of species in peril from trade is high. Illegal trade is a latent threat for all newly described cactus species. For example, the precise locality of *Mammillaria luethyi* is known to only a small number of experts to protect the wild population from unsustainable collecting.

Knowledge and practicality

In contrast to many animal groups assessed to date, levels of Data Deficient (DD) listings among cacti are relatively low. Only 129 species (8.7%) of cacti were assessed as DD (Supplementary Table 1), meaning that there was inadequate information to assess their extinction risk based on distribution and/or population data. This is markedly lower than for vertebrate groups: 15% for mammals, 25% for amphibians and 46% for sharks and rays[5,26]. Low levels of DD cactus assessments mirror those of other less speciose plant groups that have been fully assessed to date (for example conifers, 1%; cycads, 1%; mangroves, 4%; sea grasses, 12%[5,26]). This is likely to be a consequence of the relatively greater ease of gathering data on the occurrence of plants than for many mobile cryptic animal species. It suggests that in practice assessing the status of at least some major plant groups is not substantially more challenging in terms of data availability than for animal groups that have attracted considerably more conservation attention.

For cacti, the global species assessment process took about 6 h per species and cost US$167 per taxon, including paid staff time, volunteered expert and staff time and workshop costs. Thus in a year, one full-time person looking at all aspects of an assessment (contacting experts, organizing workshops, fundraising) could evaluate around 363 species. Combined with the above results this clearly demonstrates that, with relatively moderate resources, global species assessments can be undertaken for major plant taxa; overall, the assessment for cacti cost less than many standard research grants issued through major funding bodies. Moreover, as evidenced here, such exercises can reveal patterns in the distribution and prevalence of threats that are fundamentally different from those for other groups that have been globally assessed. Indeed, these exercises are integral to planning conservation activities to protect more effectively all threatened biodiversity at a global scale. To assess all described plant species by 2020, based on the resources used for the global cactus assessment, it would take at least 157 people working fulltime on assessments for 5 years at a cost of approximately US$47 million. The goal of evaluating a substantial proportion of plant species and thereby contributing to the achievement of the Global Strategy for Plant Conservation is thus both undoubtedly achievable and vital.

Methods

Existing data were gathered from the literature for each of 1,478 cactus species on their distribution, population trend, habitat preference and ecology, conservation actions, use and trade (see Materials and Methods for details). This included over 38,000 occurrence point records, which were used to generate preliminary range maps. This information was evaluated at a series of nine formal expert workshops, and then used by the participants to evaluate the extinction risk of each species using the IUCN Red List Categories and Criteria[2].

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Author contributions

B.G. and K.J.G. jointly created, developed and led the project. C.H.T., A.F., H.M.H., J.S., M.S., N.P.T., M.T., A.M.A, S.A., H.J.A.N., M.A.B., R.T.B., D.B., P.B., C.A.B., A.B., F.C., M.C.B., R.C.D., M.D.V.P., P.H.D., W.A.D.B., R.D., L.F.Y., R.S.F., B.F.M., W.A.F.M., G.G., C.G.H., L.R.G.T., M.P.G., P.C.G., B.H., K.D.H., J.G.H.O., M.H., M.I.I., R.K., J.L., J.L.L.D., C.R.L.S., M.L., M.C.M., L.C.M., J.G.M.A., C.M., J.M., E.M., R.A.M., J.M.N., V.N., L.J.O., P.O.B., A.B.P.F., D.J.P., J.M.P., R.P., J.R.G., P.S.P., E.S.M., M.S., J.M.S.M.C., S.N.S., J.L.T.M., T.T., M.T., M.T., T.V., T.R.V., M.E.V., H.E.W., S.A.W., D.Z., J.A.Z.H. contributed to the species assessment process. G.C.P., J.P.D., R.I. and C.P. conducted the analyses. B.G. and K.J.G. drafted the manuscript and this was commented on by all of the authors.

Additional information

Supplementary information is available online. Reprints and permissions information is available online at www.nature.com/reprints. Correspondence and requests for materials should be addressed to B.B. and K.J.G.

Competing interests

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