Appendix A. Methods: Compiling the threats map

To identify threats to plants in the Sonoran Desert, we started with the IUCN threats classification scheme, which provides a numeric key for referring to threats in Red List assessments (IUCN CMP 2006). The threats are categorized into the following: Development, Agriculture, Energy production, Biological Resource Use, Human Intrusions & Disturbance, Invasive species, Genetics, & Disease, Pollution, Climate change & severe weather, Geological events, and other (Table 1). Threats are further divided into subcategories reflecting more granular characterizations which specify the specific nature of threats. We evaluated which threats were relevant to the Sonoran Desert and searched for available layers.

We created a threats map using ArcGIS Pro, beginning with a 10 km hexbin layer covering the entirety of North America, and narrowed this to the outermost shape of existing shapefiles of the Sonoran Desert (Brown, Love, and Pase 1979; Brown, Brennan, and Unmack 2007, NextGen 2019). We added existing available layers of threats across the Sonoran Desert. The layers were not trimmed and the extent of the data is specified in Table 2. As data quality varies across national and state boundaries, some datasets cover only a fraction of the region of interest. We applied the IUCN threats classification scheme to the GIS layers, so that similar threat layers could be grouped together. For example, Mexico oil and gas wells and U.S. oil and gas wells would both be categorized as 3.1 Oil & Gas Drilling.

Point and line shapefiles were buffered to fully represent the actual impacted area. For example, for mines, which were represented by points, we took an average diameter of the actual impacted area, based on visual examination of disturbances of aerial imagery using GIS, and created buffers around those points. Similarly, roads were only represented by lines, so a buffer was added based on the right of way distance for Arizona state highways (30m on each side). Size of buffers is included in Table 2.

To minimize processing time for users, and generalize threats across larger areas, the area of individual threat layers was calculated within each hexbin analysis unit. For vector layers, the summarize within tool was then used to calculate the area of each layer representing a threatening process within the generalized hexbins. For raster datasets (land cover, urban growth, etc.), the zonal statistics as table tool was used. The resulting tables were then joined to the original hexbin layer. The area of each hexbin falling within a protected area was also calculated. All calculations and transformations were performed with layers projected into the World Cylindrical Equal Area projection.

The model calculates a threat to the target species by the co-location of a threat and a species distribution point in the same hexbin. A hexbin shapefile is a GIS layer that divides the area into hexagons of a designated area based on the distance between centroids of two adjacent cells. Each 10 km^2 hexbin represents 115.30 km^2. The use of hexbins to generalize both polygon and raster data reflecting threats allows for generalization of threat types at a variety of scales, reduces the need for complex and

time-consuming computations that might otherwise be needed, and provides flexibility to the end user to choose an appropriate scale of application. In selecting the size of hexbin to use, we balanced the limitations of sampling plant records relative to the actual distribution of the species, and the need to limit the scope of threats assigned to a specific habitat. The use of the hexbin allows for the assumption that the plant species is distributed beyond the collection point. When comparing results from 10 km^2 and 25 km^2 hexbins, we found that the 25 km^2 hexbins covers a wider extent of a species-threat interactions, which may introduce threats that are not actually impacting the species due to distance.

The inclusion of hexbins and buffers on the map helped eliminate the need to closely delineate the decay distance from the threat. Decay distance is a characteristic of a threat to consider in terms of the diffusion of the threat across distance (Muhammed et al. 2021). Using a hexbin to define the overlap between the threat and the target species provides buffer space for threats to extend beyond their defined boundaries. However, some threats may not be a large threat beyond their specific footprint and therefore should only be considered if very close to existing habitat or populations. For example, the existence of a dam in a hexbin may not pose a threat to a plant outside of a certain disturbance zone. Alternatively, a power transmission corridor may not extend very far, relative to a 50 km^2 hexbin, but often powerlines are kept denuded or mowed, destroying much of the vegetation directly underneath. The threats indicated by the model are a proposed possible scenario, which should be verified by the user.

Buffers

Buffer distance was determined based on suspected impact of threats on plants living in the area. Buffer distance was based largely off an examination of aerial imagery unless another suitable estimation could be made.

Commercial and Industrial Areas

For power plants, disturbance distance was based off aerial imagery. For each category of potential threat, a random subset of 15 points was selected. Measurements were taken at each site to determine the long axis of the greatest extent of disturbance that was visible in imagery. Half of the average of these values for each category was used as the buffer distance. Buffer distance for landfills was set to reflect the mean area of municipal landfills in the United States. Total area of 1,232 landfills examined by Powell *et al*. (2016) was 510 km^2 giving an average of 0.414 km^2. Based on this, a value of 363 m was set for landfill buffer distance. There is considerable variation in landfill size, and Arizona landfills fall in the upper range of landfill area. For the Sonoran Desert, landfill area should be considered a conservative estimate. Buffer distance for the US border was set at 30 m based on an examination of aerial imagery.

Power plants were found to vary greatly in disturbance area and were calculated as follows:

Type	**Distance (m)**
Battery	42
Coal	1,240
Natural Gas	390
Nuclear	880
Other	170
Petroleum	230

Oil and Gas Drilling

The impacted area surrounding oil and gas wells is highly variable and dependent largely on the type of well and the characteristics chosen to define "disturbance". As such, application of a single buffer distance is, at best, an approximation of disturbance distances. Various estimates exist for the impact of oil and gas wells in different habitats. A buffer distance of 70 m was chosen in this analysis following the mean well pad area (1.5 hectares) from the Permian Basin as determined by Pierre *et al*. (2020). Other estimates in semi-arid grasslands and shrublands are somewhat lower than this value, including a value of 0.915 hectares for wells in the upper Colorado River Basin (Buto et al. 2010). The upper value was considered more appropriate to this analysis partially because habitat within the Permian Basin is much more similar to Sonoran habitats and partially, because estimates relying on well pad area inherently underestimate the spatial impact of disturbance as access roads, habitat fragmentation, and fugitive dust are not taken into account by these estimates. All wells in dataset (even non-active wells) were included in the analysis. This was done as the status of remediation efforts is not well understood, nor is there clear indication that wells are permanently inactivated.

Mining and Quarrying

Mining and quarrying impacts were determined using the same method used for power plants. For active mines, a value of 645 m was selected, while aggregate mines were found to have a buffer distance of 430 m.

Renewable Energy

Buffer distances for renewable energy sources were determined using the same method outlined for conventional power plants. Buffer distances were calculated as follows.

Type	Distance (m)
Biomass	255
Geothermal	155
Solar	265
Wind	4,765

Roads and Railroads
A standard value of 30 m was applied to all roads and railroads included in the dataset.

Utility and Service Corridors
A standard value of 30 m was applied to all roads and railroads included in the dataset.

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Table 1. Threats categories and types of disturbance included in the threats map. The threats key and description is based on a threats classification scheme (version 3.2) developed by IUCN (IUCN CMP 2006). "Represented on threat map?" indicates whether the type of disturbance is represented in the map by one or more layers. Code is the reason why the threat was not included in the threats map: 1 = not relevant; 2 = not available. Categories in bold highlight critical information gaps of the threats map. Asterisk indicates layers in which projections are available on the threats map (urbanization and fire). The border wall is included in 1.2 . A double asterisk indicates categories that were included under 1.2.

Threat category	Type of Disturbance	Key:	Represented on threat map?	Code
Residential and Commercial Development (1)	Housing & Urban Areas*	1.1	yes	
Residential and Commercial Development (1)	Commercial & Industrial Areas*	1.2	yes	

Residential and Commercial Development (1)	Tourism & Recreation Areas	1.3	No	2
Agriculture & Aquaculture (2)	Annual & Perennial Non-Timber Crops	2.1	yes	
Agriculture & Aquaculture (2)	Livestock Farming & Ranching	2.3	yes	
Energy Production & Mining (3)	Oil & Gas Drilling	3.1	yes	
Energy Production & Mining (3)	Mining & Quarrying	3.2	yes	
Energy Production & Mining (3)	Renewable Energy	3.3	yes	
Transportation & Service Corridors (4)	Roads & Railroads	4.1	yes	
Transportation & Service Corridors (4)	Utility & Service Lines	4.2	yes	
Humans Intrusions & Disturbance (6)	Recreational Activities	6.1	No	2
Humans Intrusions & Disturbance (6)	War, Civil Unrest & Military Exercises**	6.2	No	1
Natural System Modifications (7)	Fire & Fire Suppression*	7.1	Yes	
Natural System Modifications (7)	Dams & Water Management/Use	7.2	Yes	
Invasive & Other Problematic Species, Genes & Diseases (8)	**Invasive Non-Native/Alien Species/Diseases**	**8.1**	**Incomplete (only burros and horses)**	
Pollution (9)	Garbage & Solid Waste**	9.4	No	2
Agriculture & Aquaculture (2)	Wood & Pulp Plantations	2.2	no	1
Agriculture & Aquaculture (2)	Marine & Freshwater Aquaculture	2.4	Yes	
Transportation & Service Corridors (4)	Shipping Lanes	4.3	no	1
Transportation & Service Corridors (4)	Flight Paths	4.4	no	2
Biological Resource Use (5)	**Hunting & Collecting Terrestrial Animals**	**5.1**	**no**	**2**
Biological Resource Use (5)	**Gathering Terrestrial Plants**	**5.2**	**no**	**2**

Biological Resource Use (5)	Logging & Wood Harvesting	5.3	no	1
Biological Resource Use (5)	Fishing & Harvesting Aquatic Resources	5.4	no	1
Humans Intrusions & Disturbance (6)	Work & Other Activities	6.3	no	2
Natural System Modifications (7)	Other Ecosystem Modifications	7.3	no	2
Invasive & Other Problematic Species, Genes & Diseases (8)	Problematic Native Species/Diseases	8.2	no	2
Invasive & Other Problematic Species, Genes & Diseases (8)	Introduced Genetic Material	8.3	no	2
Invasive & Other Problematic Species, Genes & Diseases (8)	Problematic Species/Diseases of Unknown Origin	8.4	no	2
Invasive & Other Problematic Species, Genes & Diseases (8)	Viral/ Prion-induced Disease	8.5	no	2
Invasive & Other Problematic Species, Genes & Diseases (8)	Diseases of Unknown Cause	8.6	no	2
Pollution (9)	Domestic & Urban Waste Water	9.1	no	2
Pollution (9)	Industrial & Military Effluents	9.2	no	2
Pollution (9)	Agricultural & Forestry Effluents	9.3	no	2
Pollution (9)	Air-borne Pollutants	9.5	no	2
Pollution (9)	Excess Energy	9.6	no	2
Geological Events (10)	Volcanoes	10.1	no	1
Geological Events (10)	Earthquake/Tsunamis	10.2	no	1
Geological Events (10)	Avalanche/ Landslides	10.3	no	1
Climate Change/Severe Weather (11)	**Habitat Shifting & Alteration**	**11.1**	**no**	**2**
Climate Change/Severe Weather (11)	Droughts	11.2	no	2

Climate Change/Severe Weather (11)	Temperature Extremes	11.3	no	2
Climate Change/Severe Weather (11)	Storms & Flooding	11.4	no	2
Climate Change/Severe Weather (11)	Other Impacts	11.5	no	2
Other Options (12)	Other Threat	12.1	no	2

Table 2: List of layers included on the threats map, description of layer data, Geographic extent, source, and buffer size (if included).

Attribute Name	**Threat Code**	**Description**	**Geographic extent**	**Underlying Geometry Type**	**Citation**	**Buffer Distance**
T010100	1.1	Housing and Urban Areas	Canada, Mexico, US	Raster	Commission for Environmental Cooperation 2015	
T010200	1.2	Military Installations	US	Polygon	US Department of Defense 2018	
T010200	1.2	Border Wall/Clearance	US	Line	TIGER/Line Shapefile 2023	30 m
T010200	1.2	Landfills	US	Point	ORNL et al. 2022	363 m (based on Powell *et al*. 2016)
T010200	1.2	Power Plants	US	Point	HIFLD 2022A	Variable dependin g on type
T020104	2.1.4	Annual & Perennial Non-timber Crops	Canada, Mexico, US	Raster	Commission for Environmental Cooperation 2015	
T020304	2.3.4	Cattle Grazing (BLM leases)	US	Polygon	BLM Admin State *et al*. 2023	

T020304	2.3.4	Cattle Grazing (USFS)	US	Polygon	USFS 2022	
T020304	2.3.4	State Grazing Allotments (AZ)	US (Arizona)	Polygon	Arizona State Land Department and Arizona Land Resource Information System 2020	
T020304	2.3.4	State Grazing Allotments (CO)	US (Colorado)	Polygon	Colorado State Land Board 2023	
T020304	2.3.4	State Grazing Allotments (Montana)	US (Montana)	Polygon	Montana Public Library 2023	
T020304	2.3.4	State Grazing Allotments (NM)	US (New Mexico)	Polygon	NM SLO 2022	
T020304	2.3.4	State Grazing Allotments (OR)	US (Oregon)	Polygon	State of Oregon 2022	
T020304	2.3.4	State Grazing Allotments (UT)	US (Utah)	Polygon	UAGRC 2009	
T020304	2.3.4	State Grazing Allotments (WA)	US (Washington)	Polygon	Washington State Department of Natural Resources Southeast Region 2023	
T020304	2.3.4	State Grazing Allotments (WY)	US (Wyoming)	Polygon	Wyoming Office of State Lands and Investments 2023	
T020403	2.4.3	Marine and Freshwater Aquaculture	Mexico, US	Raster	Commission for Environmental	

					Cooperation 2015	
T030100	3.1	Oil and Gas Drilling	US	Point	ORNL and ANL 2023	70 m (Pierre *et al*. 2020)
T030200	3.2	Mines (Mexico)	Mexico	Point	CONAP et al. 2020	645 m
T030200	3.2	Mines (US)	US	Point	ESRI and USGS 2006	645 m
T030200	3.2	Mines (Aggregates)	US	Point	HIFLD 2017	431 m
T030300	3.3	Renewable Power Plants	US	Point	HIFLD 2022A	Variable based on type
T040100	4.1	Primary and Secondary Roads	Canada, Mexico, US	Lines	National Transportation Atlas Database 2022	30 m
T040100	4.1	Railroads	Canada, Mexico, US	Lines	National Transportation Atlas Database 2020	30 m
T040200	4.2	Electrical Transmission Lines	US	Lines	HIFLD 2022B	
T070103	7.1.3	Fire Risk	US	Raster	Dillon *et al*. 2015	
T070211	7.2.11	Dams	Canada, Mexico, US	Polygon	Lehner *et al.* 2011	
T080102	8.1.2	Horses and Burros	US	Polygon	Bureau of Land Management 2017	
Protected		Protected Areas	Canada, Mexico, US	Polygon	IUCN and UNEP-WCMC 2023	

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