Contributed Paper

A GIS-Based Comparison of the Mexican National and IUCN Methods for Determining Extinction Risk

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Abstract: *The national systems used in the evaluation of extinction risk are often touted as more readily applied and somehow more regionally appropriate than the system of the International Union for Conservation of Nature (IUCN). We compared risk assessments of the Mexican national system (method for evaluation of risk of extinction of wild species [MER]) with the IUCN system for the 16* Polianthes *taxa (Agavaceae), a genus of plants with marked variation in distribution sizes. We used a novel combination of herbarium data, geographic information systems (GIS), and species distribution models to provide rapid, repeatable estimates of extinction risk. Our GIS method showed that the MER and the IUCN system use similar data. Our comparison illustrates how the IUCN method can be applied even when all desirable data are not available, and that the MER offers no special regional advantage with respect to the IUCN regional system. Instead, our results coincided, with both systems identifying 14 taxa of conservation concern and the remaining two taxa of low risk, largely because both systems use similar information. An obstacle for the application of the MER is that there are no standards for quantifying the criteria of habitat condition and intrinsic biological vulnerability. If these impossible-to-quantify criteria are left out, what are left are geographical distribution and the impact of human activity, essentially the considerations we were able to assess for the IUCN method. Our method has the advantage of making the IUCN criteria easy to apply, and because each step can be standardized between studies, it ensures greater comparability of extinction risk estimates among taxa.*

Keywords: Agavaceae, estimation of distribution area, extinction risk assessment, IUCN, MER, *Polianthes*

Una Comparación Basada en SIG de los Métodos Nacionales Mexicanos y de la IUCN para la Determinación del Riesgo de Extinción

Resumen: *Los sistemas nacionales utilizados en la evaluación del riesgo de extinción de especies a menudo se presentan como más fáciles de aplicar y más apropiados regionalmente que el sistema de la Unión Internacional para la Conservación de la Naturaleza (IUCN). Comparamos los sistemas de riesgo de extinción de especies de México (MER Métodos de Evaluación del Riesgo de Extinción de las Especies Silvestres en México), y el de la IUCN para 16 taxa del género* Polianthes *(Agavaceae), género con marcada variación en el tamaño del área de distribución de sus especies. Usamos una novedosa combinación de datos de herbario con Sistemas de Información Geográfica (SIG) y modelos de distribución geográfica de especies, para proporcionar estimaciones rápidas y repetibles del riesgo de extinción. Nuestro método mostró que los sistemas MER y IUCN utilizan datos similares. Nuestra comparación ilustra como el método de la IUCN puede ser empleado aún cuando todos los datos deseables no se encuentran disponibles y que el MER no ofrece ninguna ventaja*

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regional con respecto al sistema de IUCN. Por el contrario, nuestros resultados muestran que ambos métodos coinciden ya que los dos sistemas identificaron 14 taxa con problemas importantes para su conservación y los restantes dos taxa con riesgo bajo, principalmente porque ambos sistemas utilizan información similar. Un problema que se presentó al aplicar el MER, fue la ausencia de parámetros para definir los criterios de condición de hóbitat y la vulnerabilidad biológica intrínseca de las especies. Si estos criterios, difíciles de cuantificar, se dejan de lado, lo que queda por evaluar son la distribución geográfica de las especies y el impacto de las actividades humanas; esencialmente los parámetros que pudimos usar con el método de la IUCN. Nuestro método tiene la ventaja de aplicar más fácilmente los criterios de la IUCN y debido a que cada paso puede ser estandarizado entre estudios, asegura una mayor posibilidad de comparación en las estimaciones del riego de extinción entre diferentes taxa.

Palabras Clave: Agavaceae, estimación del área de distribución, evaluación del riesgo de extinción, IUCN, MER, *Polianthes*

Introduction

One of the key priorities of conservation biology is to ascertain the degree to which species are threatened (IUCN 2006). To achieve this objective in the face of rapid extinction rates, it is crucial to evaluate species extinction risk regardless of the quality of available data (IUCN 2001, 2006). Recently, it has been debated whether the use of the International Union for Conservation of Nature (IUCN 2001, 2008) system of risk assessment is superior to current national systems in categorizing risk (e.g., Mexico's method for evaluation of risk of extinction of wild species [MER]) (Grammont & Cuarón 2006; Cuarón & Grammont 2007; Soberón & Medellín 2007). Grammont and Cuarón (2006) concluded that, with the exception of the Canadian system, which is an approximation of the IUCN method, national systems have serious deficiencies and should be replaced by the IUCN method.

Nevertheless, the IUCN system is frequently criticized as requiring an unrealistically large amount of difficult-to-acquire data. This excessive complexity is presented as the justification for the use of simpler or somehow more regionally appropriate national systems. Because each country has different policies and conservation threats, and conservation decisions are made at the national level, many argue that national systems better satisfy the needs of individual nations and make it unlikely that there is a single most suitable system of threatened species categorization (e.g., Soberón & Medellín 2007).

To address this controversy, we compared the Mexican MER and the IUCN system. Our method estimates extinction risk based on species occurrence data obtained from scientific collections and on environmental variables combined with a geographic information system (GIS) approach (cf. Willis et al. 2003). We modeled species distributions with known occurrence data and climatic variables to identify the extent of likely habitat for the species. In addition, we used newly available maps of land use to estimate the impact of human activities on wild populations, a central concern for extinction risk estimation. One of these maps is the so-called human footprint map (Sanderson et al. 2002), which assigns an impact value to pixels worldwide based on proximity to sources of disturbance. In a further step we assessed the presence of species in protected areas (cf. Solano & Feria 2007). A major advantage of our GIS-based approach is that it provides a readily applied methodology that is repeatable and provides estimations of extinction risk that should be more broadly comparable across taxa than those of current methods. For the present exercise, we required a group of species with variation in extinction risk among taxa.

We selected as a study system *Polianthes* (Agavaceae), a genus of plants with marked variation in distribution sizes, a factor often associated with the differences in extinction risk. All 16 *Polianthes* taxa are endemic to Mexico, which allowed us to compare the global IUCN method (IUCN 2008) with the MER. When species have transnational ranges the use of the regional guidelines (IUCN 2003) is necessary (Miller et al. 2007). Several species in this genus have been cultivated and used for medicinal, ornamental, and ceremonial practices since pre-Hispanic times, with most uses centering on the fragrant inflorescences of cream-colored flowers. Currently, *Polianthes* (especially *P. tuberosa*) is economically important worldwide as cut flowers and as a key source of essential oils for the perfume industry (Steenstra & Brundell 1986; Solano 2000; Waithaka et al. 2001). *Polianthes* offers a useful study system because of marked variation in conservation status, with 5 of the 14 named species of *Polianthes* listed as rare by the IUCN (IUCN 1997; category "rare" is no longer included in the IUCN system) and in need of "special protection" under Mexican law (SEMARNAT 2002), whereas other species are common and widespread. We show that both the IUCN and regional systems can be readily applied, and that both methods converge to a large extent in their estimations of extinction risk. We also offer specific observations regarding *Polianthes* taxa and comment on advantages and disadvantages of our method.

Methods

We examined 885 herbarium specimens of 14 species and three varieties of *Polianthes*. We examined material from 23 herbaria and gathered information from databases at the Comisión Nacional para el Conocimiento y Uso de la Biodiversidad (Conabio) and the World International Network REMIB (http://www.conabio.gob.mx/remib/remib.html). In addition, we conducted fieldwork from 1994 to 2004 as part of a study of the taxonomy and distribution of the genus. We used 1:50,000 topographical maps to georeference historical records and performed cartographic analyses with ArcView 3.2 (ESRI 1999).

MER Criteria and Categories

To list organisms for protection, a MER assessment has been required by Mexican law since 2002 (SEMARNAT 2002). There are four risk criteria in the MER, each divided into risk categories with numerical scores, with higher numbers denoting higher risk. The total score is calculated by adding the results from the four criteria. The criteria and categories can be summarized as follows. Geographical distribution (criterion A) is assessed with respect to the total area of Mexico (1,964,375 km^2). Species occurring in <5%, between 5 and 15%, between 15 and 40%, and >40% of the national territory are, respectively, highly restricted (risk category 4), restricted (category 3), widely distributed or moderately restricted (category 2), and widely distributed (category 1). Habitat condition (criterion B) is assessed with respect to the natural requirements of the target taxon and has three score levels: hostile or highly limiting (3), intermediate to limiting (2), and favorable or only slightly limiting (1). The "intrinsic biological vulnerability" of a species (criterion C) includes, for example, factors such as reproductive strategy, life history, phenology, habitat requirements, genetic variation, and recruitment rates. The scores for this criterion are high (3), medium (2), and low (1). Finally, negative impact of human activity (criterion D) is scored as high (4), medium (3), and low (2). Species with total scores between 12 and 14, of 10 or 11, and of 9 or below are, respectively, in danger of extinction (EE), threatened (T), and of little current risk (LR).

We based specimen geographic distribution (criterion A, expressed as area of occupancy [AOO]; i.e., "area within its 'extent of occurrence,' which is occupied by a taxon, excluding cases of vagrancy" [IUCN 2006]), extent of occurrence (EOO, "area contained within the shortest continuous imaginary boundary which can be drawn to encompass all the known, inferred or projected sites of present occurrence of a taxon, excluding cases of vagrancy" [IUCN 2006]), and current distribution area (CA) on Solano and Feria (2007) (Table 1). We calculated the AOO for all taxa by superimposing a grid of 1 × 1 km cells onto the species distributional data and counting the number of cells occupied by each species.

We represented the EOO for each taxon (except *P. palustris* and *P. venustuliflora* because of the small

Table 1. Geographic distribution per species of *Polianthes* determined on the basis of area of occupancy (AOO), extent of occurrence (EOO), and current distribution area (CA).[a]

Species	*AOO[b] (km^2)*	*AM[c] (%)*	*AOO[d] (km^2)*	*AM[c] (%)*	*EOO[e] (km^2)*	*AM[c] (%)*	*CA[f] (km^2)*	*AM[c] (%)*
Polianthes bicolor	6	0.0003	24	0.0012	1,285	0.0654	1,413	0.0719
P. densiflora	5	0.0003	20	0.0010	3,616	0.1841	1,462	0.0744
P. geminiflora var. *clivicola*	33	0.0017	132	0.0067	52,349	2.6649	34,843	1.7737
P. geminiflora var. *geminiflora*	118	0.0060	448	0.0228	282,650	14.388	179,414	9.1334
P. geminiflora var. *pueblensis*	10	0.0005	40	0.0020	156.81	0.0080	17	0.0009
P. graminifolia	12	0.0006	40	0.0020	11,232	0.5718	1,898	0.0966
P. howardii	7	0.0004	28	0.0014	1,236	0.0629	187	0.0095
P. longiflora	31	0.0016	124	0.0063	29,138	1.4833	15,303	0.7790
P. montana	6	0.0003	24	0.0012	22,355	1.1380	3,444	0.1753
P. multicolor	18	0.0009	72	0.0037	16,003	0.8147	8,727	0.4443
P. nelsonii	25	0.0013	100	0.0051	57,933	2.9492	54,925	2.7961
P. oaxacana	3	0.0002	12	0.0006	40.246	0.0020	262	0.0133
P. palustris[g]	1	0.0001	4	0.0002	–	–	–	0.0000
P. platyphylla	29	0.0015	116	0.0059	38,577	1.9638	43,021	2.1901
P. sessiliflora	59	0.0030	228	0.0116	194,662	9.9096	155,867	7.9347
P. venustuliflora	3	0.0002	8	0.0004	–	–	20	0.0010

[a] *Taken and modified from Solano and Feria (2007).*
[b] *Area of occupancy (AOO) based on 1 × 1 km grids.*
[c] *Percentage of the total area of Mexico (AM), which is 1,964,375 km^2.*
[d] *Area of occupancy (AOO) based on 2 × 2 km grids.*
[e] *Extent of occurrence (EOO).*
[f] *Current area (CA) of distribution based on ecological niche modeling by GARP, biogeographic provinces, subbasins, and current land use.*
[g] *Likely already extinct.*

number of distributional data) as the area encompassed by a convex polygon enclosing all occurrence points. All distributional data (i.e., points) were joined by the shortest distance with straight lines, and the distances between the points were measured, allowing calculation of arithmetic mean distance between localities. We used the following environmental variables to calculate CA for 12 species and three varieties: total annual precipitation, absolute maximum temperature, absolute minimum temperature, mean maximum temperature, mean minimal temperature, aspect (sine and cosine transformations), slope, soil type, elevation, and solar radiation. We built models of potential distributions on the basis of these environmental variables with the desktop computer implementation of GARP (http://www.lifemapper.org/desktopgarp; see Solano & Feria [2007] for details). There are at least 16 different methods for predicting species distributions. It was not our intention to compare the performance of the different species distribution prediction approaches, and we recommend Elith et al. (2006), Peterson et al. (2007), and Phillips (2008) for discussions of the pros and cons of the different methods. We restricted predicted distributions to those Mexican biogeographic provinces and subbasins in which each species has been recorded.

It seems difficult to assess habitat condition (criterion B) independent of criterion D, the impact of human activity. One approach is to assess habitat condition without considering the impact of human activity. Nevertheless, human activity is precisely the factor that has led to the degradation of *Polianthes* habitat, which makes an assessment of the habitat condition in the absence of human activity an academic exercise of little use for the estimation of extinction risk (cf. Olson et al. 2005). Therefore, we had no choice but to assess criteria B and D with overlapping methods. We examined these criteria by superimposing human footprint data (Sanderson et al. 2002 [www.ciesin.columbia.edu/wild_areas]) to determine the scale of threats throughout the distribution of each *Polianthes* species. The human footprint is derived from a 1 × 1 km raster data set produced by compiling scores from population density, land transformation, accessibility, and electrical power infrastructure data, and the data set yields an estimate of human impact (Sanderson et al. 2002) ranging from 0 to 100, with scores of 0–10 denoting pristine areas. Based on this index, the risk scores for criterion B (habitat condition) were as follows: 50 or higher, hostile or highly limiting (3); 25–49, intermediate to limiting (2); and 0–25, favorable or only slightly limiting (1). The scores for criterion D (impact of human activity) were 50 or higher, high (4); 25–49, medium (3); and 0–25, low (2). In addition, we contrasted original vegetation with current land use. First we gathered information on the type of vegetation in which the species was found based on herbarium label information. Then we superimposed collection localities on a map of "potential vegetation," that is, a map of hypothetical original vegetation types (Rzedowski 1990 [http://conabioweb.conabio.gob.mx/metacarto/metadatos.pl]). We then further superimposed the localities where specimens of *Polianthes* have been collected on a map of current vegetation and land use (Conabio 1999 [http://conabioweb.conabio.gob.mx/metacarto/metadatos.pl]) as an additional measure of historical impacts within species distributional areas.

With regard to criterion C, there are two intrinsic biological characteristics that may make *Polianthes* species vulnerable. First, they are wind-dispersed geophytes, a life-form thought to be particularly sensitive to habitat alteration (Williams et al. 2005), and second, many species require very specific microhabitats (e.g., only in crevices in volcanic rocks). Nevertheless, we lacked specific information regarding how these characteristics might contribute to the vulnerability to extinction in *Polianthes*. Moreover, even if these data were available, the MER provides no guidelines as to how intrinsic vulnerability should be assessed and scaled. As a result we simply assigned a score of medium to all species.

IUCN Criteria and Categories

As outlined by IUCN (2001), for a species to be identified as threatened, it must meet one of five criteria (A–E). Additional criteria that the taxon qualifies for at lower threat categories may be included in the documentation. These criteria specify thresholds of (A) reduction in population size; (B) geographic range size coupled with decline, fragmentation, or fluctuations; (C) small population size coupled with decline, fragmentation, or fluctuations; (D) very small population size or restricted distribution; and (E) quantitative analysis showing a specified probability of extinction (IUCN 2008). Herbarium data can give an approximation of the species geographic distribution (criterion B) (Willis et al. 2003). This information coupled with GIS analysis can help in the assessment of extinction threats, estimation of population reduction (criterion A), and detection of very small or restricted populations (criterion D). When applying the IUCN method, it is common to find that the data are not sufficient to address one or more criteria. The identification of which data are missing or inadequate is one of the most important steps of the IUCN method. In our case we applied parts of criteria A, B, and D and found that for all species census data were lacking. Such data are necessary for the assessments of population size (criterion C) and for quantitative estimates of extinction risk (criterion E), which identify priorities for further work.

The threat level of a species is expressed on the basis of the highest category of threat for which a species qualifies, with the criterion and subcriteria that qualify being specified (e.g., critically endangered: A2cd; B1 + 2de;

C2a[i]). A species can be assigned to one of nine categories of extinction risk (IUCN 2001, 2008): extinct (EX), no doubt the last individual of a taxon has died; extinct in the wild (EW), taxon is only known to occur in cultivation or captivity; critically endangered (CR), extremely high risk of extinction in the wild; endangered (EN), very high risk of extinction in the wild; vulnerable (VU), high risk of extinction in the wild; near threatened (NT), close to qualifying for a threatened category (CR, EN, or VU) in the near future; least concern (LC), taxon that does not qualify for any of the above categories and is regarded as widespread and abundant; data deficient (DD), inadequate information to evaluate extinction risk; and not evaluated (NE), taxon has not yet been assessed for extinction risk.

Criterion A has four categories (A1–A4) and five subcriteria (a–e). Our data best fit the criterion A2c (A2, "[p]opulation reduction observed, estimated, inferred, or suspected in the past where the causes of reduction may not have ceased OR may not be understood OR may not be reversible, based on any of (a) to (e) under A1," where (c) measures "a decline in area of occupancy. . ., extent of occurrence . . . and/or habitat quality" [IUCN 2008:13]).

To estimate decline in AOO (IUCN 2008), we calculated the suitable habitat modeled with GARP and subtracted the transformed habitats based on a map of land use (Conabio 1999 [http://conabioweb.conabio.gob.mx/metacarto/metadatos.pl]) to provide an estimate of the percentage of habitat loss. We used this figure as a proxy for the estimation of population loss. Given that *Polianthes* species are poorly dispersed geophtyes, we expected this procedure to be a reasonable approximation of decline.

Criterion B (geographic range) consists of a comparison between alternative situations. In B1 geographic range is expressed as EOO, with the goal of ascertaining whether EOO falls below three critical thresholds (<100 km^2, $<5{,}000$ km^2, $<20{,}000$ km^2) versus an assessment of AOO. This assessment of AOO requires determination of which threshold applies to the focal taxon (<10 km^2, <500 km^2, <2000 km^2) and two of the following three subcriteria. Subcriterion a measures whether the species is severely fragmented or the number of locations is 1, 5, or 10. Subcriterion b assesses continuing decline in EOO, AOO, area, extent and quality of habitat, the number of locations or subpopulations, and the number of mature individuals. This criterion encompasses virtually all information used in our focal national system for the assessments of AOO, EOO, and CA.

Following IUCN (2006) guidelines we also assessed the AOO of the species by superimposing a grid of 2 $\times$ 2 km cells onto the species distributional data and counting the number of cells occupied by each species (Table 1). The number of locations was estimated by considering the number of subbasins where the species occur. Subbasins were chosen to represent locations because they indicate the location of barriers for *Polianthes* species dispersal (Solano & Feria 2007) and can be considered a "geographically or ecologically distinct area in which a single threatening event can rapidly affect all individuals of the taxon present" (IUCN 2008:39). We estimated continuing decline—"recent, current or projected future decline which is liable to continue unless remedial measures are taken" (IUCN 2008:24)—with the proposed original vegetation of the area where the species occurs, which was based on a map of potential vegetation (Rzedowski 1990) and the transformation of that vegetation assessed by superimposing the most recent available land-use map (http://conabioweb.conabio.gob.mx/metacarto/metadatos.pl).

We also examined the human footprint score levels from Sanderson et al. (2002) to determine the scale of threats throughout the distribution of *Polianthes*. We considered areas with human footprint values >25 to be subject to threats. Here we used the same score levels that are used for the MER criterion D. Finally, we superimposed the localities where the species have been collected on a map of the terrestrial protected regions (Conabio 2004) and natural protected areas (INE 1999). Terrestrial protected regions are areas of high biodiversity and threat that represent some of the most eligible habitats for conservation action, but they currently lack legal protection, whereas natural protected areas are protected by federal statute. For a species to be assigned to a particular IUCN category of threat (CE, E, or V) it had to meet thresholds for all three criteria evaluated (Table 2). "Continuing declines at any rate can be used to qualify taxa under criteria B" because taxa under consideration for criterion B are already characterized by restricted ranges (IUCN 2006).

Criterion D "identifies very small or restricted populations" (IUCN 2008), and again a species qualifies for listing based on this category if it meets one of two alternatives. In the first, the number of mature individuals is assessed relative to threshold values. Such data have never been collected for *Polianthes*, so we were unable to address this concern. However, we were able to test our data against the second threshold, whether or not AOO fell below 20 km^2 or the number of locations was ≤ 5. We examined the AOO and number of locations for *Polianthes* taxa.

Results

We were able to assign extinction risk categories based on both the MER (Table 3) and the IUCN (Table 4) for all *Polianthes* species with the exception of *P. geminiflora* var. *geminiflora* and *P. sessiliflora*. For most species the classifications of both methods were in agreement concerning the level of risk extinction (Fig. 1). Of the five species currently listed as subject to "special protection"

Table 2. Subcriteria of the International Union for Conservation of Nature (IUCN) criterion B.

Category	*Criterion B*	*Locations*	*Decline**
Critically endangered (CR)	area of occupancy <10 km^2 or extent of occurrence <100 km^2	1	HF 50–100
Endangered (EN)	area of occupancy <500 km^2 or extent of occurrence $<5{,}000$ km^2	≤ 5	HF 25–50
Vulnerable (VU)	area of occupancy $<2{,}000$ km^2 or extent of occurrence $<20{,}000$ km^2	≤ 10	HF 0–25
Least concern (LC)	area of occupancy $\geq 2{,}000$ km^2 or extent of occurrence $\geq 20{,}000$ km^2	>10	HF 0–25

**The IUCN guidelines stipulate that "A continuing decline is a recent, current or projected future decline (which may be smooth, irregular or sporadic) which is liable to continue unless remedial measures are taken. Fluctuations will not normally count as continuing declines, but an observed decline should not be considered as a fluctuation unless there is evidence for this" (IUCN 2001, 2008). Continuing declines are used in two different ways in the criterion. Continuing declines at any rate can be used to qualify taxa under criterion B. This is because taxa under consideration for criterion B are already characterized by restricted ranges or small population size (IUCN 2008). The human footprint (HF; Sanderson et al. 2002) is derived from a 1 × 1 km raster data set produced by compiling scores from population density, land transformation, accessibility, and electrical power infrastructure data, and the data set yields an estimate of human impact (Sanderson et al. 2002) ranging from 0 to 100, with scores of 0–10 denoting pristine areas. Score: ≥50, hostile or highly limiting (high decline); 25–49, intermediate to limiting (medium decline); 0–25, favorable or only slightly limiting (low decline).*

under Mexican law (SEMARNAT 2002), *P. densiflora* and *P. howardii* should have their classification raised to "in danger of extinction", *P. longiflora* and *P. platyphylla* should become "threatened", and *P. palustris* should be considered "likely already extinct." Detailed descriptions for all *Polianthes* species are provided (see Supporting Information). With the available data, we were able to assess all species with respect to criterion B, nine species with respect to criterion A, and five species with respect to criterion D. Most species had a higher risk category based on criterion B. Only two species had a category of threat assigned based on criterion A (*P. geminiflora* var. *pueblensis* and *P. longiflora*), and five species' threat assignments were based on criterion D (vulnerable) (Tables 4 & 5).

Geographic Distribution and Locations

Four species and one variety occurred in only one location (subbasin), five species occurred in more than one but less than five locations, and four species and two varieties occurred in more than five locations (Table 4). Some locations, primarily in the Sierra Madre Occidental and Transvolcanic Mexican Belt, had six (Río Armeria, Río Huaynamota, and Río Santiago-Guadalajara) or five species (Río Verde-Grande, Río Ameca-Atenguillo, and Río Lerma-Chapala).

Habitat Conditions, Human Influence, and Decline

Although habitat conditions varied from species to species, in most cases habitats have been transformed

Table 3. Results of method of evaluation of risk extinction of wild species for Mexico (MER) for *Polianthes* species.

	Risk criterion					
Species	*A*[a]	*B*[b]	*C*[c]	*D*[d]	*Total score*[e]	*Conservation status*[e]
Polianthes bicolor	4	2	2	3	11	T
P. densiflora	4	3	3	4	14	EE
P. geminiflora var. *clivicola*	4	2	2	2	10	T
P. geminiflora var. *geminiflora*	3	2	1	2	8	LR
P geminiflora var. *pueblensis*	4	2	3	3	12	EE
P. graminifolia	4	2	2	3	11	T
P. howardii	4	2	3	4	13	EE
P. longiflora	4	2	2	3	11	T
P. montana	4	3	2	4	13	EE
P. multicolor	4	2	2	3	11	T
P. nelsonii	4	2	2	3	11	T
P. oaxacana	4	3	2	4	13	EE
P. palustris	4	3	2	4	14	EX
P. platyphylla	4	2	2	3	11	T
P. sessiliflora	3	2	1	3	9	LR
P. venustuliflora	4	2	2	3	11	T

[a]Geographic distribution in Mexico: 4, very restricted (<0.5% of Mexican territory); 3, restricted (5–15% of Mexican territory).
[b]Habitat condition: 3, hostile or highly limiting; 2, intermediate to limiting; 1, favorable or only slightly limiting.
[c]Intrinsic biological vulnerability of a species: 3, high; 2, medium; 1, low.
[d]Impact of human activity: 4, high; 3, medium; 2, low.
[e]Key: 14, extinct (EX); 12 or 13, in danger of extinction (EE); 10 or 11, threatened (T); 9 or less, not currently at risk (LR); extinct (EX). See text for explanation of scores and Supporting Information for species descriptions.

Table 4. Results of the International Union for Conservation of Nature (IUCN) method for *Polianthes* species based on criteria A, B, and D.

Species	*Geographic distribution*[a]	*Decline (%)*[b]	*Locations*[c]	*Continuing decline*[d]	*Summary*	*Status*[e]
Polianthes bicolor	AOO, EOO, CA	<30	2	medium	B1 + 2ab(ii), D2	EN
P. densiflora	AOO	<30	1	high	B2ab(ii), D2	CR
P. geminiflora var. *clivicola*	AOO	<30	10	low to medium	B2ab(ii)	VU
P. geminiflora var. *geminiflora*	EOO, CA	<30	20	low to high	B1ab(ii)	LC
P geminiflora var. *pueblensis*	AOO, CA	>80	1	high	A2c, B2ab(ii), D2	CR
P. graminifolia	AOO, CA	>30	2	medium	A2c, B2ab(ii), D2	EN
P. howardii	AOO	<30	3	medium to high	B2ab(ii), D2	EN
P. longiflora	AOO	>50	10	high	A2c, B2ab(ii)	EN
P. montana	AOO, CA	>30	3	medium to high	A2c, B2ab(ii), D2	EN
P. multicolor	AOO	>30	3	medium to high	A2c, B2ab(ii), D2	EN
P. nelsonii	AOO	<30	6	medium to high	B2ab(ii)	VU
P. oaxacana	AOO, EOO	<30	1	high	B1 + 2ab(ii), D2	CR
P. palustris	AOO	<30	1	high	B2ab(ii), D2	EX
P. platyphylla	AOO	<30	8	low to high	B2ab(ii)	VU
P. sessiliflora	AOO	<30	16	low to high	B2ab(ii)	LC
P. venustuliflora	AOO, CA	<30	1	medium	B2ab(ii)	EN

[a] *The IUCN criteria A, B, and D are considered. Abbreviations are defined in Table 1.*
[b] *Decline (criterion A) calculated by superimposing maps of habitat suitability over maps of land use.*
[c] *Assessed by counting the subbasins where the species are distributed. Detailed calculations are in Table 5.*
[d] *Continuing decline (criterion B) is measured based on the human footprint scores (0–10, wildlands; near 100, most transformed habitats).*
[e] *Only criteria for the highest category of threat that the taxon qualifies for are listed (CR, critically endangered; EN, endangered; EX, extinct; VU, vulnerable; and LC, least concern).*

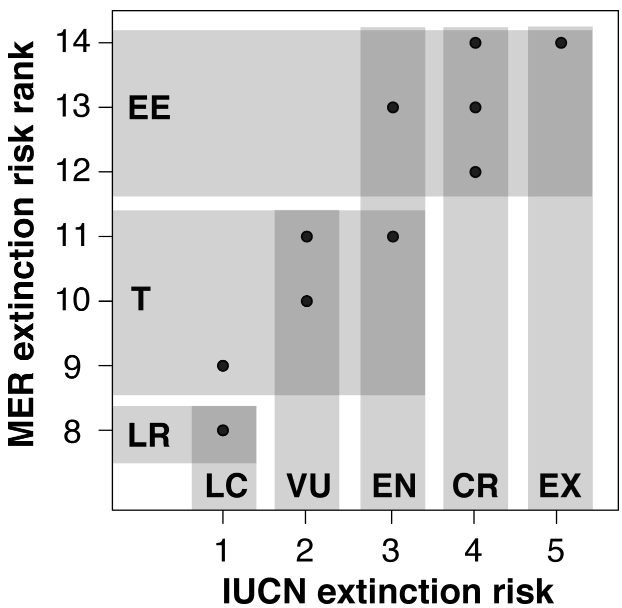

Figure 1. Comparison of the Mexican national system (MER) with the International Union for Conservation of Nature (IUCN) system extinction risk estimates for Polianthes*. We assigned numerical ranks to the IUCN risk estimates as shown in the graph to illustrate that, in general, species considered at high risk under the MER are similarly assessed by the IUCN criterion B (MER extinction risk ranks: EX, extinct; EE, in danger of extinction; T, threatened; LR, not currently at risk; IUCN ranks: CR, critically endangered; EN, endangered; VU, vulnerable; LC, least concern).*

into a series of denuded grazing lands, agricultural areas, and urban zones. Goats, sheep, and cattle were the main threats for most species, with *P. densiflora* strongly affected by feral pigs as well. Human footprint scores ranged from 0 to 93 (mean 36.17 [SD 18], $n = 145$), and the distributional areas for populations of at least eight species and two varieties had human footprint scores >50, which indicates human influence was very high throughout the range of the genus. Based on habitat suitability and estimates of land transformation, most species lost <30% of their natural habitats, but *P. graminifolia, P. montana*, and *P. multicolor* lost >30%, *P. longiflora* >50%, and *P. geminiflora* var. *pueblensis* >80%.

Four species and two varieties occurred in both natural protected areas and terrestrial protected regions (*P. geminiflora* var. *geminiflora, P. geminiflora* var. *clivicola, P. longiflora, P. montana, P. nelsonii*, and *P. sessiliflora*). Five species occurred in some terrestrial protected regions (*P. bicolor, P. densiflora, P. multicolor, P. oaxacana,* and *P. platyphylla*). Finally, three species and one variety (*P. geminiflora* var. *pueblensis, P. graminifolia, P. howardii*, and *P. venustuliflora*) were not found in any of the terrestrial protected regions or natural protected areas. These four species were classified as "in danger of extinction" by the MER and critically endangered by the IUCN. The preceding eight species and one variety did not occur in any natural protected areas, and none of these areas or terrestrial protected regions are in the area of historical occurrence of the likely extinct *P. palustris*.

Table 5. Decline score (IUCN criterion A) calculated by superimposing maps of habitat suitability on maps of land use.

Species	Habitat quality: suitable (km^2)	Habitat quality: suitable but transformed (km^2)	Decline (%)	Critically endangered >80%	Endangered >50%	Vulnerable >30%
Polianthes bicolor	1,810.32	1,413	21.95			
P. densiflora	1,672.38	1,462	12.58			
P. geminiflora var. *clivicola*	48,134.22	34,843	27.61			
P. geminiflora var. *geminiflora*	189,414.42	179,414	5.28			
P. geminiflora var. *pueblensis*	737.58	17	97.7	X		
P. graminifolia	3,366.42	1,898	43.62			X
P. howardii	218.88	187	14.57			
P. longiflora	32,910.66	15,303	53.50		X	
P. montana	6,087.6	3,444	43.43			X
P. multicolor	16,081.98	8,727	45.73			X
P. nelsonii	65,124.78	54,925	15.66			
P. oaxacana	334.02	262	21.56			
*P. palustris**	-	-	-			
P. platyphylla	54,072.48	43,021	20.43			
P. sessiliflora	165,867.72	155,867	6.029			
P. venustuliflora	23.94	20	16.46			

*Likely extinct.

Discussion

In the Mexican endemic *Polianthes*, both the MER and the IUCN methods yielded similar results, with the species of greatest conservation risk being identified similarly by both methods (Fig. 1). By the same token, *P. geminiflora* var. *geminiflora* and *P. sessiliflora* (Tables 3 & 4) were identified as of low conservation concern by both methods. We contend that the national MER seems to provide no special insight that cannot be gleaned from the IUCN method, and the IUCN method can be applied even when all desirable data are not available. Furthermore, our results show that our method of assessing species decline, which involves modeling species distributions based on species collection and environmental data, along with the use of Sanderson et al.'s (2002) human footprint index, is an efficient means of producing extinction risk evaluations that are comparable between taxa and geographical areas.

Geographic Distribution and Locations in MER and IUCN

Geographic range size estimation is the criterion most often used to assess extinction risk (Gaston 2003), and both the MER and the IUCN methods rest strongly on this parameter. Nevertheless, there is little consensus regarding how range size should be estimated. Although the IUCN method provides guidance in this respect, the MER does not specify any particular method for assessing the geographic distribution of species, a significant weakness of the method because even slight differences in the methods (e.g., in base map resolution) can lead to strong differences in the extent of species distributions that are inferred. To remedy this problem we see no reason why the MER cannot incorporate an explicit method for measuring distribution, with AOO, EOO, and maps of species' potential distribution used toward this end as proposed by IUCN (2008).

The reliability of extinction risk assessments is often compromised by biases in collection data, particularly for species with very few collections or disjunct occurrences. As a consequence of the sparseness of collections, calculating the AOO by counting the number of cells occupied by each species tends to underestimate the true distribution of a species, whereas calculating the EOO based on the minimum convex polygon defined by all known localities typically overestimates the area occupied. Furthermore, EOO cannot be calculated with fewer than three point localities, a problem for species such as *P. venustuliflora* that is only found in two locations. IUCN (2008:29) states that EOO "may exclude discontinuities or disjunctions within the overall distributions of taxa." Unfortunately it is difficult to know which areas to omit from a calculation of EOO, thereby introducing an element of uncertainty and often subjectivity (e.g., Schatz et al. 2000; Willis et al. 2003; Golding 2004). Maps of modeled species distributions allow suitable and unsuitable environments to be distinguished within the EOO, and because species are generally not found in a continuum across suitable habitats, AOO in combination with maps of species distribution is a good tool with which to assess the area of distribution of a species. It should be noted, however, that for correct application of the IUCN guidelines, EOO must also be considered in risk assessments. Given that factors such as size of grid cells directly influence outcomes of extinction risk assessments when measurements of AOO are made, with threat status increasing as grid cell size decreases (Willis et al. 2003), we followed the IUCN (2008) recommendation to use two different sizes of grid cells (1 × 1 km and 2 × 2 km).

Herbarium data can help generate a preliminary estimate of the number of locations where a species would be expected to occur (Willis et al. 2003).We used herbarium data in combination with GIS applications to assess the number of locations based on main barriers (subbasins) for *Polianthes* species and on proximity to urban or semiurban zones where the species may be harvested. Because these protocols are based on clearly specified quantitative parameters, they substantially increase repeatability in the assessment of the number of locations. Ideally, our method should be used in combination with verification of its predictions with ground-based investigations.

Our GIS-based method does not include the fine details of the biology of a species in generating extinction risk estimates. It could be argued that two species can have identical ranges but differing extinction risks because of biological differences (e.g., long-lived trees vs. understory herbs) (cf. Sjöström & Gross 2006). We argue that our omission is, in fact, an advantage compared with systems such as the MER, whose criterion C reflects "intrinsic biological vulnerability." There is no standard for transforming the panoply of differences in resource acquisition, systems of mating, population structuring, habitat preferences, and interactions with other species into a standardized system of four categories that can be compared among species. As a result the evaluations and ranks of this criterion in the MER are left to the subjective evaluation of each researcher (e.g., one might consider density-dependent pollination a major factor placing a species at risk whereas another might not). We are concerned that excessive emphasis on intrinsic biological vulnerability could jeopardize comparability between the estimates of risk. Because the central purpose of extinction risk estimation is to guide allocation of conservation efforts, comparability is a paramount consideration.

MER and IUCN Not So Different After All

The national systems for evaluating conservation status are often cited as offering advantages with respect to the IUCN method (e.g., that conditions specific to each country can be taken into account or that the IUCN method is too difficult; Grammont & Cuarón 2006; Soberón & Medellín 2007). Our evaluation of the MER and the IUCN systems yielded nearly identical results because both examine essentially the same factors. Both the MER and the IUCN systems take distribution size into account and both incorporate the impact of human activity. Moreover, with appropriate methods, the IUCN approach is applied just as readily as the MER.

Our results also serve to highlight the subjectivity and redundancy of the MER. In addition to the problems outlined above with regard to criterion C ("intrinsic biological vulnerability") criterion B ("condition of habitat") is impossible to assess independent of human activity (criterion D). It is difficult to imagine a situation in which the habitat of a species is unsuitable for that species except in the case of human alteration. Olson et al. (2005) suggest that a situation in which all populations except peripheral ones have been destroyed could represent a case in which the natural habitat would be considered unfavorable, but this also invokes human perturbation. However, for virtually if not all cases, the "condition of habitat" criterion of the MER can be thought of as lumped with criterion D (impact of human activity) and disregarded.

Our study of *Polianthes* illustrates the subjectivity of the MER condition of habitat criterion. Although the results of one study seem to show that geophytes fare poorly in an Australian semiurban grassland (Williams et al. 2005), we have no information regarding how *Polianthes* species, which are also geophytes, react to disturbance over the long term. As in all MER studies, the risk rank we assigned, in this case "intermediate" for all species, was arbitrary. Assigning all species the same rank factors out this criterion. So if criteria B and C of the MER are for all practical purposes excluded, we are left with criteria A and D, distribution, and the impact of human activities: exactly the same considerations embodied in the IUCN criteria A2, B, and D, which underscores the fundamental lack of substantial differences between the national and the international systems.

Conclusion

Estimation of extinction risk is one of the key components of any conservation plan. Existing data and methodological advances, such as the GIS-based approach we used here, can provide estimates of extinction risk that are both rapid and readily compared among studies, both crucial considerations if extinction risk assessments are to form part of conservation decisions at national and international levels. Our results make the advantages of national systems over the IUCN system seem exaggerated, as are the difficulties in the implementation of the IUCN criteria. Moreover, what may be lost in terms of complications in implementing the IUCN method is gained by ensuring internationally comparable risk estimations, a vital concern for establishing global conservation priority species and deciding international funding priorities. These considerations are crucial as the number of species that are threatened increases relative to the resources available for their conservation.

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Supporting Information

Details of extinction risk estimations for the taxa of *Polianthes* are available as part of the on-line article (Appendix S1). The authors are responsible for the content and functionality of these materials. Queries (other than absence of the material) should be directed to the corresponding author.

Literature Cited

Comisión Nacional para el Conocimiento y Uso de la Biodiversidad (Conabio). 1999. Uso de suelo y vegetación modificado por Conabio. Escala 1: 1000000. Conabio, México, D.F., México.

Comisión Nacional para el Conocimiento y Uso de la Biodiversidad (Conabio). 2004. Regiones terrestres prioritarias. Escala 1:1000000. Conabio, México, D.F., México.

Cuarón, A., and P. de Grammont. 2007. Shortcomings of threatened species categorization systems: reply to Soberón and Medellín. Conservation Biology **21:**1368–1370.

Elith, J., et al. 2006. Novel methods improve prediction of species' distributions from occurrence data. Ecography **29:**129–151.

ESRI (Environmental Systems Research Institute). 1999. ArcView GIS 3.2. ESRI, Redlands, California.

Gaston, K. J. 2003. The structure and dynamics of geographic ranges. Oxford University Press, Oxford, United Kingdom.

Golding, J. S. 2004. The use of specimen information influences the outcomes of red list assessments: the case of southern African plant specimens. Biodiversity and Conservation **13:**773–780.

Grammont, P., and A. Cuarón. 2006. An evaluation of the threatened species categorization systems used on the American continent. Conservation Biology **20:**14–27.

INE (Instituto Nacional de Ecología). 1999. Red del sistema nacional de áreas naturales protegidas. INE, México, D.F., México.

IUCN (International Union for Conservation of Nature). 1997. Cactus and succulent plants: status survey and conservation plan. IUCN, Gland, Switzerland, and Cambridge, United Kingdom.

IUCN (International Union for Conservation of Nature). 2001. IUCN Red List categories and criteria. Version 3.1. IUCN Species Survival Commission, Gland, Switzerland, and Cambridge, United Kingdom. Available from http://www.redlist.org/info/categories_criteria2001.html (accessed July 2007).

IUCN (World Conservation Union). 2003. Guidelines for application of IUCN Red List criteria at regional levels. Version 3.0. IUCN Species Survival Commission, IUCN, Gland, Switzerland, and Cambridge, United Kingdom. Available from http://www.iucn.org/themes/ssc/redlists/regionalguidelines.htm (accessed July 2007).

IUCN (International Union for Conservation of Nature). 2006. Guidelines for using the IUCN Red List categories and criteria. Version 6.2. Standards and Petitions Working Group of the IUCN SSC Biodiversity Assessments Sub–Committee, IUCN, Gland, Switzerland. Available from http://www.iucn.org/webfiles/doc/SSC/RedList/RedListGuidelines (accessed July 2007).

IUCN (International Union for Conservation of Nature). 2008. Guidelines for using the IUCN Red List categories and criteria. Version 7.0. Standards and Petitions Working Group of the IUCN SSC Biodiversity Assessments Sub-Committee, IUCN, Gland, Switzerland. Available from http://www.iucn.org/webfiles/doc/SSC/RedList/RedListGuidelines (accessed July 2007).

Miller, R. M., et al. 2007. National threatened species listing based on IUCN criteria and regional guidelines: current status and future perspectives. Conservation Biology **21:**684–696.

Olson, M. E., J. A. Lomeli, and N. I. Cacho. 2005. Extinction threat in the *Pedilanthus clade* (Euphorbia, Euphorbiaceae), with special reference to the recently rediscovered *E. conzatti* (*P. pulchellus*). American Journal of Botany **92:**634–641.

Peterson, A.T., M. Papes, and M. Eaton. 2007. Transferability and model evaluation in ecological niche modeling: a comparison of GARP and MaxEnt. Ecography **30:**550–560.

Phillips, S.J. 2008. Transferability, sample selection bias and background data in presence-only modelling: a response to Peterson et al. (2007). Ecography **31:**272–278.

Rzedowski, J. 1990. Vegetación potencial. IV.8.2. Atlas nacional de México. Volume II. Escala 1:4 000 000. Instituto de Geografía, Universidad Nacional Autónoma de México, México, D.F., México

Sanderson, E. W., M. Jaiteh, M. A. Levy, K. H. Redford, A. V. Wannebo, and G. Woolmer. 2002. The human footprint and the last of the wild. BioScience **52:**891–904.

SEMARNAT (Secretaría de Medio Ambiente y Recursos Naturales). 2002. Norma Oficial Mexicana NOM–059–ECOL–2001, protección ambiental—especies nativas de México de flora y fauna silvestres—categorías de riesgo y especificaciones para su inclusión, exclusión o cambio—lista de especies en riesgo. Diario Oficial de la Federación (6 de marzo de 2002), Primera sección. Diario Oficial de la Federación, Mexico City, México.

Schatz, G. E., C. Birkinshaw, P. P. Lowry, F. Randriantafika, and F. Ratovoson. 2000. The endemic plant families of Madagascar project: integrating taxonomy and conservation. Pages 11–24 in W. R. Lourenco, and S. M. Goodman, editors. Diversité et endémisme à Madagascar. Mémoires de la Societé de Biogéographie, Paris.

Sjöström, A., and C. L. Gross. 2006. Life-history characters and phylogeny are correlated with extinction risk in the Australian angiosperms. Journal of Biogeography **33:**271–290.

Soberón, J., and R. A. Medellín. 2007. Threatened species categorization systems. Conservation Biology **21:**1366–1367.

Solano, C. E. 2000. Sistemática del género *Polianthes* L. (Agavaceae). Tesis de doctorado. Facultad de Ciencias, División de Estudios de Posgrado, Universidad Nacional Autónoma de México, México, D.F., México.

Solano, E., and T. P. Feria. 2007. Ecological niche modeling and geographic distribution of the genus *Polianthes* L. (Agavaceae) in Mexico: using niche modeling to improve assessments of risk status. Biodiversity and Conservation **16:**1885–1900.

Steenstra, D. R., and D. J. Brundell. 1986. Tuberosa: cultivation, cut flower production". Information bulletin 187. Ministry of Agriculture and Fisheries, Wellington, New Zealand.

Waithaka, K., M. S. Reid, and L. L. Dodge. 2001. Cold storage and flower keeping quality of cut tuberose (*Polianthes tuberosa* L.). Journal of Horticultural Science and Biotechnology **76:**271–275.

Williams, N. S. G., J. W. Morgan, M. J. McDonell, and M. A. McCarthy. 2005. Plant traits and local extinctions in natural grasslands along an urban–rural gradient. Journal of Ecology **93:**1203–1213.

Willis, F., J. Moat, and A. Paton. 2003. Defining a role for herbarium data in red list assessments: a case study of *Plectranthus* from eastern and southern tropical Africa. Biodiversity and Conservation **12:**1537–1552.