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Short Communication

An assessment of Red List data for the Cycadales

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Abstract
We compiled Red List data from all listed cycad taxa to determine the current status of the world's most threatened plant group. Each Red List threat category had different proportions of genera, and the genera comprised different proportions of threat categories. Each Red List threat category consisted of different proportions of Red List criteria. Each genus was composed of different proportions of Red List criteria, and every genus was represented by different proportions of listed versus non-listed species. Differences among the genera and categories were substantial, revealing no canonical characteristics that define the members of this plant group. Species that are missing from the Red List or Data Deficient deserve high priority for completion of assessment and listing. *Cycas* is the genus that may change the most as taxonomy and Red List threat assessments continue to be modified. Distinctive overviews of the Red List data such as this one provide a unique snapshot of the conservation status of the world's cycads, and should be repeated as trends evolve.

Keywords. cycad, Cycadaceae, Red List, Stangeriaceae, Zamiaceae

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Introduction

The Anthropocene marks the age of human impact on the globe as the steady decline of global biodiversity ushers in a mass extinction event [1,2]. Global biodiversity rates are steadily declining [3], and anthropogenic land modification and habitat loss seriously threaten the sustenance of terrestrial ecosystems [4-6]. Dirzo and Raven [7] assert that the loss of biodiversity is the one irreversible global environmental change our earth faces today. More studies are needed to improve global understanding of these developments.

Cycads are members of the Cycadales, the most threatened group of plant species on Earth [8-11]. This Order of gymnosperms includes the families Cycadaceae, Stangeriaceae, and Zamiaceae, and includes more than 330 species [12]. Cycads are the most ancient of contemporary spermatophytes and encompassed approximately 20% of the world's flora during the Jurassic period [11, 13]. Research on today's cycad taxa can provide a direct window to the past and reveal the characteristics that have enabled the long persistence of this group [14].

In recent decades, numerous taxonomic revisions have focused on the entire Cycadales, its families, or its genera. Detailed evaluations of taxa in the Cycadales [15-17] or the Cycadaceae [18] have examined variations in functional traits, providing a useful basis for comparing cycads as a group to global data sets. However, only a few papers examine the robust range of cycad species and traits in relation to global data sets.

A more comprehensive look at the world's most threatened plant group may improve our understanding of world-wide threats to global biodiversity. To our knowledge, the only detailed published assessments of the status of cycads were in 2003 [13, 19]. Since that time the International Union for Conservation of Nature's Red List of Threatened Species has been heavily refined and expanded (238 species in 2004 versus 303 species in 2014), with substantial and enduring cycad taxonomic revisions and assessments. Moreover, we are not aware of any recently published reports that include an intrinsic evaluation of the Red List database for all accepted contemporary cycad species. To address this research gap, we have conducted an empirical comparison of the IUCN Red List data (Red List hereinafter) of various cycad groupings. The commonalities and idiosyncrasies found could improve cycad conservation strategies on regional and global scales.

Methods

For taxonomic authority, we employed the most recently published World List [12]. We compared this list to the taxa included in the 2014 Red List to determine the proportion of accepted taxa successfully uploaded to the Red List. For each Red List entry, we created a database of the threat category and the core criteria used for determining the threat status. Threat categories included: critically endangered, endangered, vulnerable, near threatened, and least concern. The March to August 2014 database consisted of 337 entries, of which 303 were found on both the Red List and the World List. Entries on the Red List that were not confirmed on the World List were not included in our analyses. We used the database to evaluate overall trends among genera and threat categories by creating chi-square contingency tables with five approaches.

First, we organized the data into groups by threat category. We tallied the species within each genus that were listed under each threat category on the Red List. Then we added a group to include the species on the World List that were not found on the Red List, and these were added to the data as the category "not listed." Second, we worked exclusively with the 303 valid species on the Red List and organized the data into groups by genera. We tallied the number of species within each threat category that were listed under each genus on the Red List. Third, we again organized the database into groups by threat categories. The species within each criterion [20] that were listed under each category were organized into a contingency table. Fourth, we organized the database into groups by genus, and the species within each criterion that were listed under each genus were organized into a contingency table. Lastly, we created a contingency table for each genus that incorporated the number of species on the Red List and the number of species not included on the Red List in order to identify which genera have been least evaluated.

Chi-square contingency table analysis was performed on the direct counts within each table using the PROC FREQ command in SAS V 9.2. This approach tested the hypothesis that the proportions of species observed in the groups within each genus or category were similar among genera or categories.

Results

Critically Endangered cycad species accounted for 17% of the species evaluated on the 2014 Red List, whereas Endangered species accounted for 21% and Vulnerable species accounted for 24%. These data indicated that 63% of the species on the Red List were among the threatened categories.

The hypothesis that the proportions of each genus grouped within each threat category were similar was rejected ($P<0.0001$). The major genera contributing to each of the categories are readily apparent when comparing the frequency images (Appendix 1). Of the taxa that are threatened, Critically Endangered species were primarily from *Encephalartos* and *Zamia*; Endangered species were primarily from *Cycas* and *Zamia*; and Vulnerable species were primarily from *Cycas*. Data Deficient species were from *Cycas*, and described species not found on the Red List were primarily from *Cycas* and *Zamia*.

The hypothesis that the proportions of each threat category grouped within each genus were similar was rejected ($P<0.0001$). A quick view of Appendix 2 reveals general trends for each of the Cycadales genera. No two graphs exhibited a similar appearance. Of the six genera containing multiple species, only *Ceratozamia* and *Cycas* exhibited a normal shaped curve on the x-axis that ranged from most threatened on the left to least threatened on the right. In contrast, *Dioon* was skewed to the left, *Macrozamia* was skewed to the right, and *Encephalartos* and *Zamia* patterns exhibited minimal skewness. Of these six genera, *Encephalartos* emerged as the most threatened. *Microcycas* was the most threatened of the four genera with fewer than 10 species.

The hypothesis that the proportions of each criterion grouped within each threat category were similar was rejected ($P<0.0001$). Major headings of the Red List criteria are A-E. Although the details supporting each criterion are slightly different among the categories, in general A depicts a reduction in population size over time, B depicts limited geographic range, C depicts small population size combined with reduction in population, D indicates highly limited population size or range, and E employs a quantitative analysis on the probability of extinction [20]. The three official categories that define Red List threatened taxa did not exhibit similar trends among the Red List criteria (Appendix 3). Critically Endangered species were listed primarily with Criterion B, Endangered species were listed with a combination of Criteria A and B, and Vulnerable species were listed primarily with Criterion A. Criterion E was not employed for listing any of the Cycadales species.

The hypothesis that the proportions of each criterion categorized within each genus were similar was rejected ($P<0.0001$). Each genus exhibited a unique blend of criteria that the Red List employed to define its category (Appendix 4). *Encephalartos* and *Zamia* listing Criteria were split among A, B, and C. *Ceratozamia*, *Dioon*, and *Macrozamia* listing Criteria were mostly A and B. *Cycas*, *Microcycas*, and *Stangeria* listing Criteria were primarily A. *Bowenia* and *Lepidozamia* species were not included in this assessment because they were not threatened according to the Red List Categories.

The hypothesis that the proportion of listed versus not listed species within each genus was similar was rejected (P=0.0099). The vast majority of described species that have not been uploaded to the Red List to date are *Cycas* and *Zamia* species, which together accounted for 76% of the overlooked species (Appendix 5).

Discussion

Recent capabilities of assessing large data sets to illuminate general and global trends have enabled tools like ionomics [21], metabolomics [22], and web-based data analysis [23]. The Red List has been used for decades as a tool for cataloguing conservation status, for monitoring species, and for making decisions. With appropriate analysis, the robustness of the Red List is also useful for understanding global trends.

Arguing the merits and limitations of the Red List is beyond the scope of our paper, and has been done elsewhere [*e.g.,* 24]. Formal methods for calculating Red List changes within any group of organisms have been established as the Red List Index (RLI) [25]. Because the RLI focuses exclusively on category changes within a group of organisms over time, limiting evaluations of Red List data to the RLI calculator may preclude interpretations based on independent unique assessments by conservationists. IUCN-endorsed formal assessments of species groups [*e.g.,* 13, 26] are invaluable, but should not exclude the value of *ad hoc* evaluations of the quantitative data contained in the Red List. The importance of independent interpretations of Red List data can be seen in published assessments of various groups of organisms, such as birds [27], amphibians [28], marine turtles [29], and butterflies [30]. Our goal was highly exacting in addressing Red List data specific to the Cycadales in 2014. Several outcomes are noteworthy.

First, every means of interpreting the information in the Red List confirms that the world's living cycad species are exceedingly threatened. Of the 2014 Red Listed cycad species, almost two-thirds were threatened according to categories of the Red List. This confirms the 2010 assertions [11]. As more cycad species are newly described and taxonomic modifications clarify cycad classification, we believe the changes will universally increase the high threat categories and proportionally decrease the low threat categories. For example, the two most recently described Philippine *Cycas* species deserved Critically Endangered status as soon as they were described [31,32].

Second, the 34 missing species and the two Data Deficient species represent a deficiency in global cycad conservation efforts that should be corrected. The accurate assessment of international Cycadales conservation cannot be ascertained until all legitimately described taxa have been evaluated and added to the Red List by capable, informed local experts.

Third, the differences among the compared categories and genera were sizeable. No general trend emerged as canonical among our groupings within the Cycadales. For example, *Encephalartos* contained the greatest number of Critically Endangered species (Appendix 1), but was fourth on the list for Endangered species (Appendix 2). No other genus exhibited a similar pattern. Our findings underscore the fallacy of attempting to apply results from one genus or geographic region to other genera or geographic regions. For instance, Golding and Hurter [33] published a detailed assessment of the African *Encephalartos* species using Red List data, and suggested that continent-level actions are needed. Attempting to apply the African results to other continents would be useless based on our findings.

Fourth, the genera exhibiting Red List traits that may change the most in the near future can be envisaged from our results. *Cycas,* for example, contained roughly 40% of the species in the Near

Threatened and Vulnerable categories. Because *Cycas* contains so many species in these “lower” threat categories, future changes in the Red List will cause a greater relative shift toward more threatened status for *Cycas* than for the other genera. Alternatively, about 65% of the Critically Endangered cycads were *Encephalartos* and *Zamia* species. These genera cannot exhibit a greater relative shift toward more threatened status on the Red List even if these Critically Endangered species become more threatened. Thus, studies that evaluate the global status of cycads need to be conducted routinely in accordance with changing IUCN assessments to best capture these impending changes.

Fifth, the alphanumerical assignments to category and criteria information contained within the Red List are not as useful for uncovering some of the causal reasons for assigning criteria. Most species descriptions include these underlying causes in the narrative portions of the listing. For example, assigning criteria based on decline in range may be caused by habitat loss from land conversion but also caused by invasive pests that generate local extirpations and population fragmentation. The IUCN has profiled two species that demonstrate these two contrasting threats to cycad conservation [11]. The conservation efforts needed to reverse these contrasting causes for the same criterion would not be similar.

Many cycad species have been exploited throughout the world for food, spiritual, and medicinal uses [11, 34-37]. In some regions, the local cycad represents the potent cultural history of the indigenous people. Conserving these cycad species may also conserve traditional knowledge and cultural identity that are threatened by the loss of the cycad.

In summary, this straightforward technical assessment of the 2014 Red List cycad data may inform various aspects of global cycad conservation. Although every informed cycad biologist has a general understanding of the implications of our results, such widespread knowledge does little for posterity unless it is published in some form, especially if historical changes in taxonomic modifications and threat status become difficult to construct retrospectively. Conservationists may tend to focus their efforts exclusively on local species or nearby geographic regions, and thereby overlook global trends. This may lead to oversights in the significance of local knowledge and conservation efforts for global conservation strategies. Therefore, we believe a periodic overview of global data such as this paper is warranted. Our methods or any alternative empirical evaluations of the Cycadales database should be repeated periodically (in addition to the sanctioned RLI) to transfer the immense value of the evolving Red List into pragmatic outcomes of informed conservation practices. Osborne [38] suggested that a 10-year time scale is fitting for assessing cycad population changes. However, we believe this interval should be shortened to at most 5 years, given the increasing rate at which we are losing species and at which threats are arising and interacting.

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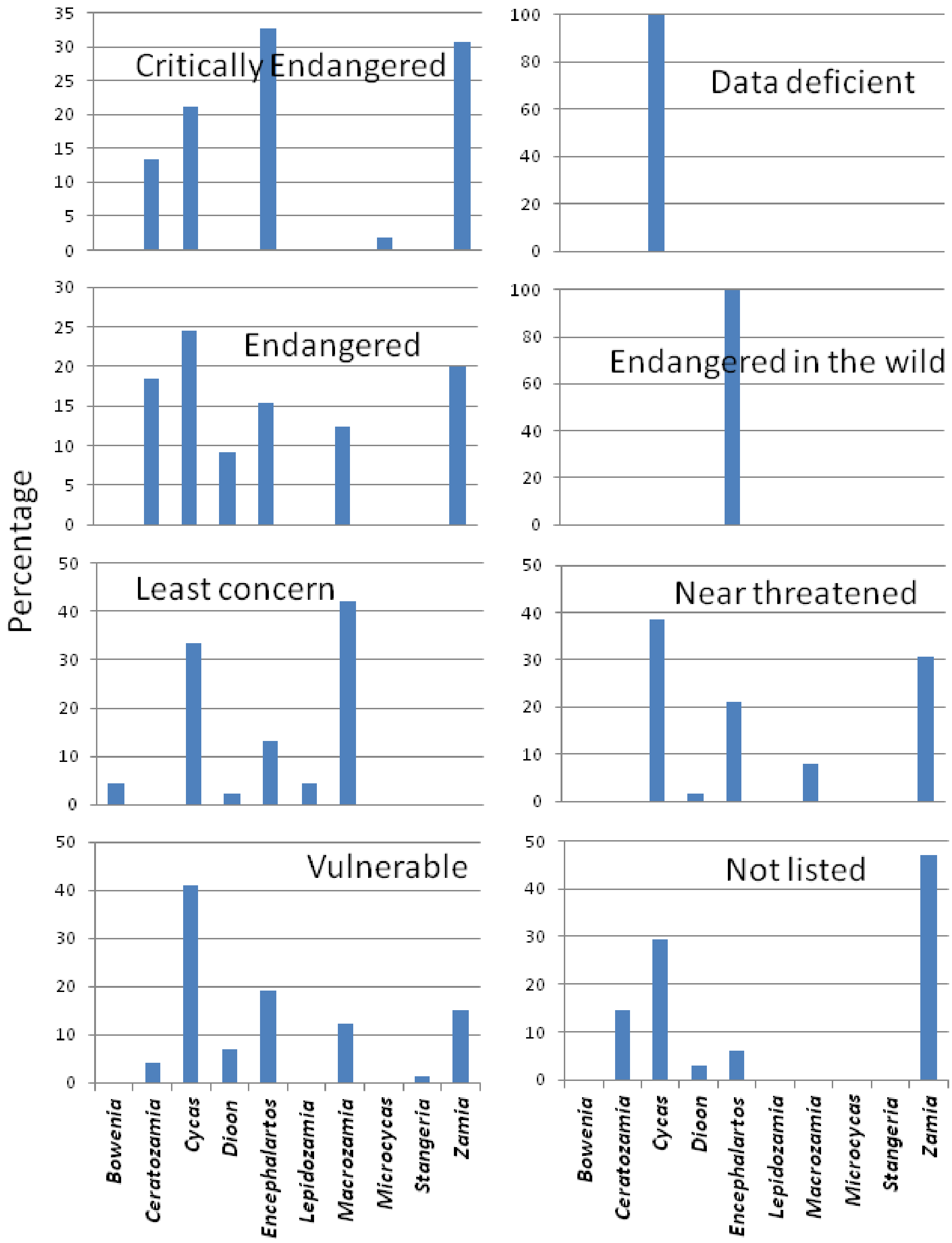
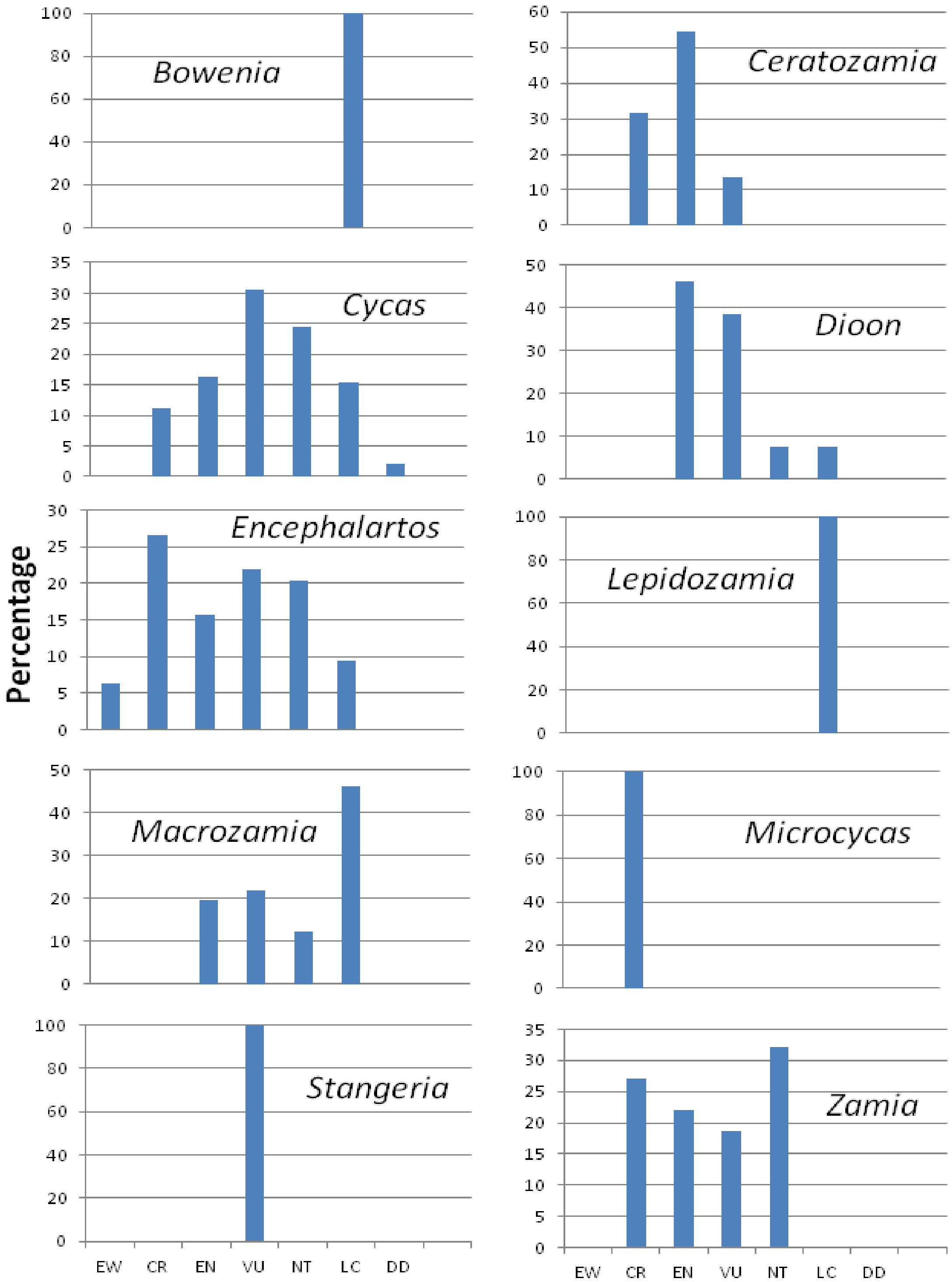
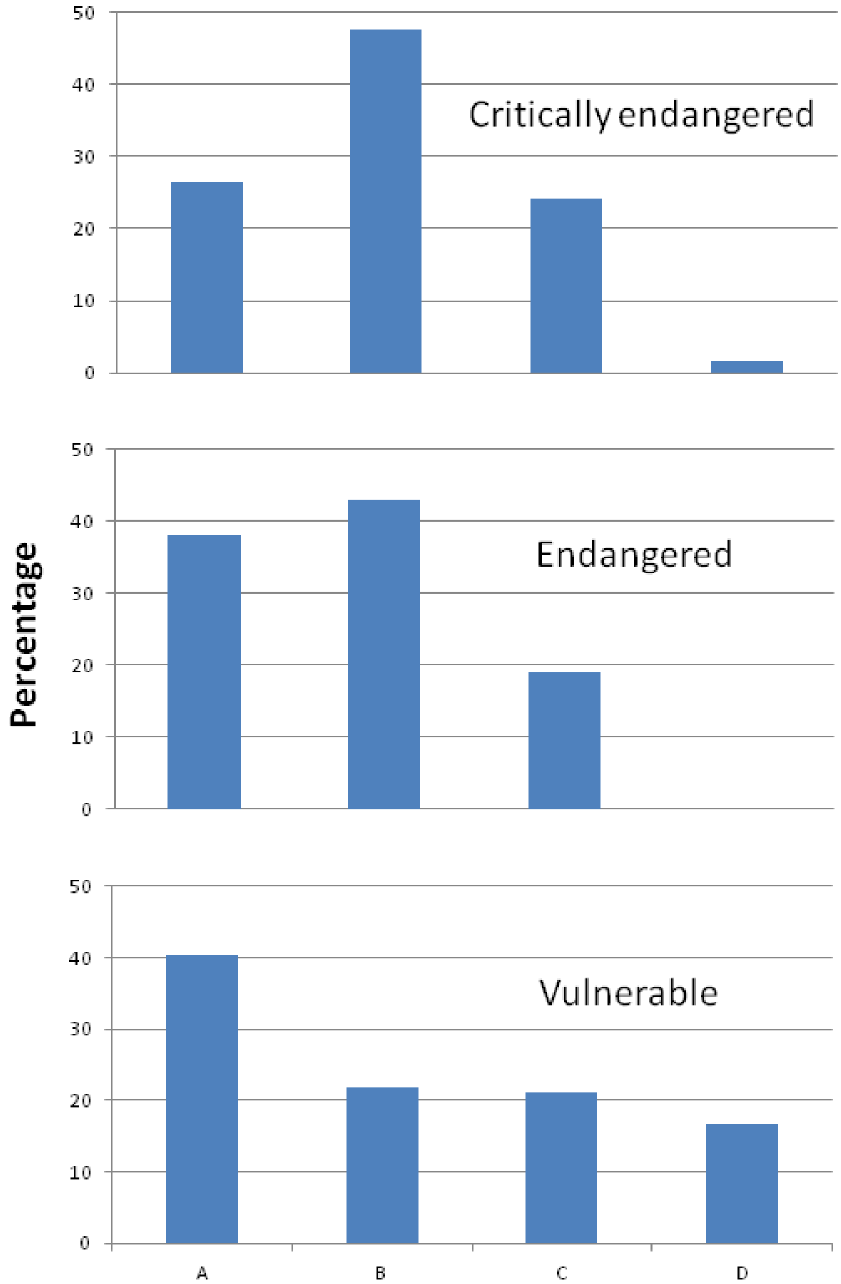
Appendix 1. The percentage of species among genera for each of seven Red List threat categories and the percentage of described species for each genus that are not contained on the Red List. Direct count frequency distributions significantly differed among the Categories (P<0.0001, 337 total entries).



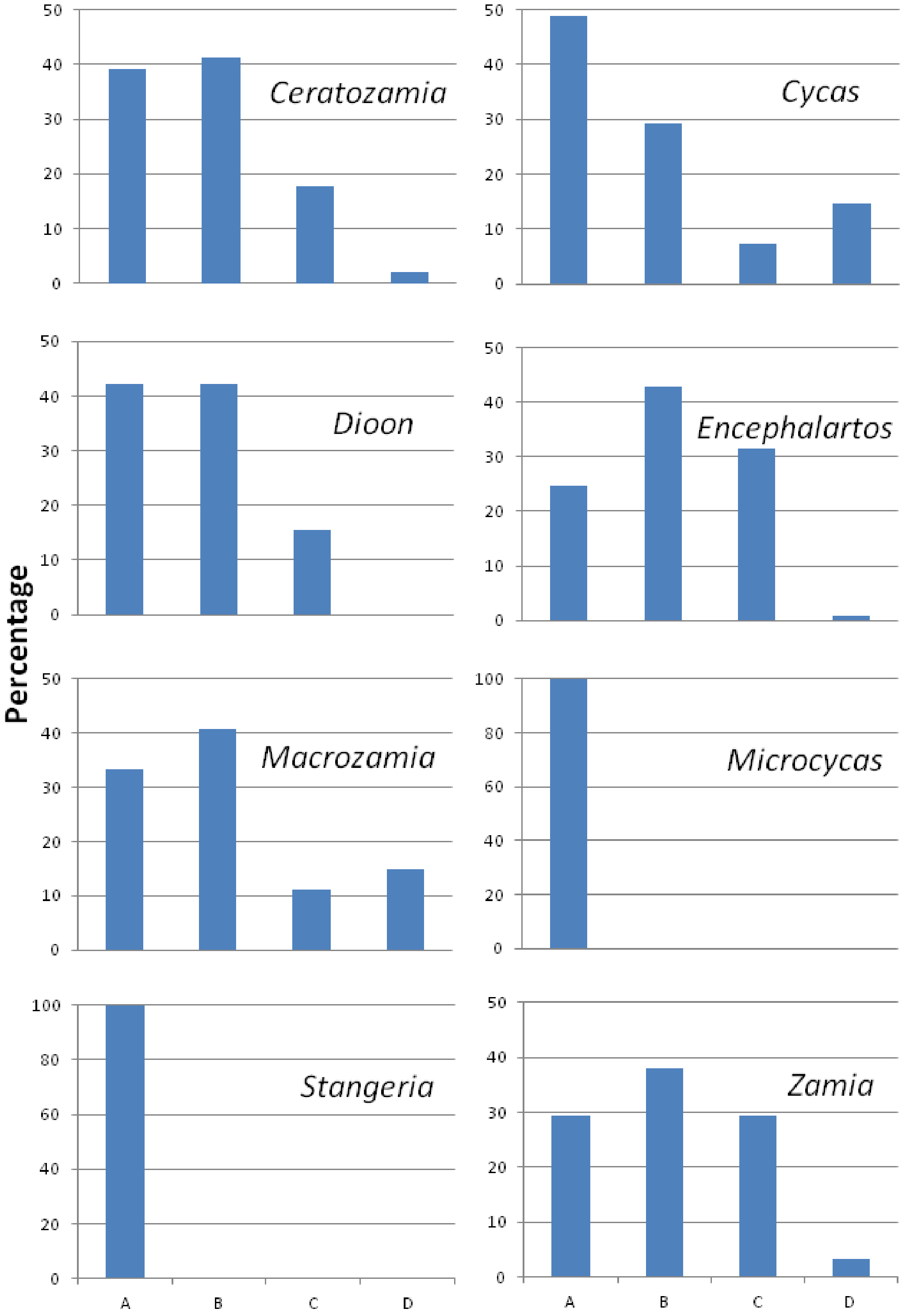
Appendix 2. The percentage of species among threat categories for each of ten genera. Direct count frequency distributions significantly differed among the genera (P<0.0001, 303 total entries). EW = Endangered in the wild. CR = Critically endangered. EN = Endangered. VU = Vulnerable. NT = Near threatened. LC = Least concern. DD = Data deficient.



Appendix 3. The percentage of species within each of four listing Criteria grouped among three major threat Categories. Direct count frequency distributions significantly differed among the Categories (P<0.0001, 385 total entries). A = reduction in population size. B = limited geographic range. C = small population size combined with reduction in population. D = highly limited population size.



Appendix 4. The percentage of species within each listing Criterion grouped by the genera that contain threatened species. Direct count frequency distributions significantly differed among the genera ($P<0.0001$, 386 total entries). A = reduction in population size. B = limited geographic range. C = small population size combined with reduction in population. D = highly limited population size.



Appendix 5. Direct counts of species uploaded to the Red List or not found on the Red List for each of ten genera. Frequency distributions significantly differed among the genera (P=0.0099, 337 total entries).