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Assessing regional differences in predation of endangered species: Implications from Texas populations of the endangered star cactus (*Astrophytum asterias*)

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ABSTRACT

Understanding threats to endangered species is one of the most critical components of implementing a successful recovery plan. For the endangered star cactus *Astrophytum asterias*, both mammalian and insect herbivory have been documented as a major threat to populations in Mexico. Herein, we focus on populations of *A. asterias* in Texas, examining how mortality threats differ from populations found in Mexico as well as among sites within Texas. Our study supports insect and mammalian herbivory as a major threat to *A. asterias* in Texas, with reductions in population sizes ranging between 16 and 54%. However, our study highlights that both regional and local differences can influence rates of mortality even in a range-restricted species such as *A. asterias* and highlights the need to assess threats at both of these levels for effective development and implementation of endangered species recovery plans.

1. Introduction

The U.S. Endangered Species Act of 1973 (ESA; United States Code, 1973) requires that a recovery plan be developed for every species listed as threatened and endangered. The objective of these species specific plans is to assist in the recovery of listed species such that their populations become self-sustaining and no longer threatened with extinction (Clark et al., 2002). Despite this mandate, researchers and policy-makers alike have identified short-comings associated with these recovery plans (Clark et al., 2002; Foin et al., 1998; National Research Council, 1995; Schemske et al., 1994; Tear et al., 1995). Clark et al. (2002) identified that threats to species had received insufficient attention in recovery plans and that those plans that linked recovery goals to species specific biological information were more likely to improve the species' status.

For endangered plants of arid systems, identifying which threat is most critical to long-term population persistence can be difficult (Valverde et al., 2004). Despite this difficulty, particular groups of plants tend to share suites of similar threats. For arid-land cacti, these threats often include over-collection for the horticultural trade (McIntosh et al., 2011), habitat disturbance (Martorell and Peters, 2005), and disease or predation (Martínez-Ávalos et al., 2007). Although documentation of individual threats at the species-specific level are available for several arid-land cacti (Godínez-Álvarez et al., 2003 and references therein), very few species have been examined for regional and or local differences in relation to specific threats such as predation. Without a detailed understanding of how threats may differ among proximal or distant populations of arid-land, endangered plants, construction of effective recovery plans will remain a challenge.

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For the federally endangered star cactus (Cactaceae: *Astrophytum asterias*), the 2003 recovery plan identified the following threats: habitat destruction, over-collection by cactus enthusiasts, inadequate regulatory protection, reduction of genetic variability through diminution of population size, and disease or predation (USFWS, 2003). Martínez-Ávalos et al. (2007) reported that damages caused by the plant pathogen *Phytophtora infestans*, a cerambycid beetle, and the Mexican ground squirrel (*Spermophilus mexicanus*) led to a reduction in population size of more than 50% in *A. asterias* in Mexico. Of these threats, Martínez-Ávalos et al. (2007) identified herbivory from *S. mexicanus* as the most important cause of death.

Although Martínez-Ávalos et al. (2007) identified threats to populations of *A. asterias* in Mexico and documented impacts of these effects on different life stages, anecdotal data collected from sites in Texas (USFWS, 2003) indicated that the demographic impacts of herbivory as well as those species responsible for herbivory-induced deaths differed from those found in Mexico. This information meant that even for a geographically restricted species such as *A. asterias*, threats facing populations may differ enough to require regional contexts to be incorporated into recovery plans. To determine how regional differences in threats may impact the existing recovery plan of the endangered *A. asterias* we sought to 1) document the species of herbivores posing a threat to *A. asterias* in Texas, 2) examine rates of mortality among different sites of *A. asterias* in Texas, and 3) relate herbivore-induced mortality to environmental variables and life-stages of *A. asterias*. In addition, we sought to compare our results from sites of *A. asterias* in Texas to the results collected from Mexican populations by Martínez-Ávalos et al. (2007). Given our different methodological approaches, geographically distinct populations, and distinct habitat types, contrasting our results to those of Martínez-Ávalos et al. (2007) provides an excellent case study to explore how regional and or local differences in mortality might influence the effective recovery of endangered species. Our comparative approach synthesizes data on mortality in *A. asterias* while highlighting differences in herbivore-induced mortality among geographically disparate populations further supporting the hypothesis that recovery plans for endangered cacti (prone to mammalian or insect-induced mortality) need to consider population variability in mortality rates at both a local and regional scale. Taking such variation into account could ultimately lead to the development of more effective recovery plans for endangered aridlands plants such as *A. asterias*.

2. Materials and methods

A. asterias is a small, globose cactus 0–3 cm tall and 2–15 cm in diameter with flat-ribbed stems divided by grooves into 8 ribs (Strong and Williamson, 2007). The plant is an obligate outcrosser whose hermaphroditic, yellowish-orange flowers can open to 15 cm in diameter (Strong and Williamson, 2007; USFWS 2003). The species is predominantly bee pollinated with *Diadasia rinconis* acting as the most important pollinator (Blair and Williamson, 2008). Oval to round fruits 1–2 cm in size contain glossy seeds with a flaring collar surrounding the hilum (Benson, 1982). Although little is known regarding seed dispersal, evidence gathered from pollen dispersal indicates that genetic neighborhoods are small enough to subdivide large patches of *A. asterias* (Blair and Williamson, 2010). The current distribution of *A. asterias* is restricted to 25 sites with one to 12 local clusters of cacti per site, covering a 145 km^2 area in south-central Starr County, Texas (Janssen et al., 2010) and 9 additional populations in Mexico, 2 in Nuevo León and 7 in Tamaulipas (Martínez-Ávalos et al., 2004). Despite its restricted distribution, *A. asterias* does not appear to have strict habitat requirements as it is found in both saline-sodic and non-saline soils, protected by nurse plants or fully exposed, and in areas either dominated by or completely devoid of *Varilla texana*. Habitats in Texas and Mexico from which *A. asterias* is known differ from one another in vegetation and soil characteristics (Birnbaum, 2009; Martínez-Ávalos et al., 2007).

In order to assess herbivore-induced mortality of *A. asterias* in Texas, we employed two methods: motion-sensor cameras and permanent plot surveys. All monitoring focused on five study sites in southern Starr County, Texas, USA (Sites 1–5, Table 1, Fig. 1). These sites were chosen based on accessibility as well as the presence of *A. asterias* (Janssen et al., 2010). Due to risks of illegal collecting activities, the exact coordinates for each of these sites have been withheld. However, a map depicting the locations of the study sites, in relation to the geographic distribution of *A. asterias*, has been included (Fig. 1).

Six vegetation transects, following a stratified random sampling design, were conducted among Sites 1, 2, 3, and 4. Each transect was 75 m (three 25-m transects) and were sampled using the line-intercept method to document the plant species within the *A. asterias* patches and determine percent dominance (cover) and percent relative dominance of these species (Birnbaum, 2009). An additional 9 patches of *A. asterias* were sampled using this method within our 75.6 km^2 study area. All vegetation surveys were

Table 1
Descriptions of five study sites used for monitoring herbivore-induced mortality of *Astrophytum asterias* in Starr County, Texas, March 2008–September 2009.

Site	Ownership	Property size	Recreational activities	Dominant vegetation (in order of dominance)	Description
1[a]	The Nature Conservancy	415-ha	Prohibited (none)	*Varilla texana* *Acacia rigidula* *Opuntia leptocaulis*	Multiple patches of *A. asterias* on property.
2[a]	Private	32-ha	Cattle ranching, hunting	*Varilla texana* *Prosopis glandulosa* *Opuntia leptocaulis*	Two verified patches of *A. asterias*.
3[a]	Private	4-ha	Goat/cattle ranching	*Varilla texana* *Opuntia leptocaulis* *Prosopis glandulosa*	Single, isolated patch of *A. asterias* next to ranch house and livestock pens.
4[a]	Private	161-ha	Hunting	*Varilla texana* *Prosopis glandulosa* *Opuntia leptocaulis*	Two verified patches of *A. asterias.*
5[b]	Private	168-ha	Hunting	*Varilla texana* *Prosopis glandulosa* *Opuntia leptocaulis*	Multiple verified patches of *A. asterias*, relatively unmodified habitat.

[a] Vegetation data from vegetation transects directly adjacent to or within study plot.
[b] Vegetation data based upon visual assessments of the major plant species present in the plot.