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BUTTERFLY BIODIVERSITY IN A THREATENED COASTAL DESERT ECOSYSTEM OF NORTHWESTERN MEXICO, WITH A FOCUS ON THE LIFE HISTORY AND ECOLOGY OF POTENTIALLY ENDANGERED SPECIES

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ABSTRACT. Butterfly biodiversity in a threatened coastal ecosystem of northwestern Mexico, near Guaymas, Sonora, is documented based on presence data obtained weekly or biweekly from November 2013 to July 2015 combined with periodic observations and collection records dating back to 1978. The survey region and adjacent coastal areas on the Gulf of California are currently undergoing major environmental degradation owing to rapid urbanization, tourism development and construction of aquaculture facilities. A total of 105 species was recorded in the study region, representing about 30% of the total number of butterfly species currently recorded for the state of Sonora. Based on specific larval host plant requirements and known geographic distributions, several species dependent upon vegetation growing in a narrow coastal strip of sand dunes, mangrove estuaries and coastal plains are suggested to be the most threatened. The ecology, systematics and conservation biology of these potentially threatened species, in addition to several other species of special interest, are discussed.

Additional key words: butterfly conservation, Sonoran Desert, thornscrub biome, threatened species, presence data

Coastal regions of the Gulf of California (also known as the Sea of Cortez) in northwestern Mexico are currently undergoing rapid and extensive ecological modifications owing to urban development, dredging of coastal lagoons for new marinas, tourism projects, and construction of aquaculture facilities (DeWalt et al. 2002, Glenn et al. 2006, Luers et al. 2006). Additional factors contributing to environmental degradation of the coastal ecosystem include invasion of exotic plants, especially buffelgrass *Pennisetum ciliare* (L.) Link (Franklin et al. 2006), the increased and currently uncontrolled use of all-terrain vehicles, cattle grazing, and runoff of agricultural pesticides and other terrestrial pollutants into coastal lagoons (McCullough & Matson 2011). Much of this ecological disturbance is centered in Sonora, but these changes are also underway on the Baja California Peninsula, including the outer Pacific coast, as well as in the mainland states of Sinaloa and Nayarit. Sensitive habitats especially threatened include subtropical sand dunes, coastal plains, mangrove estuaries and saltgrass marshes.

Most of Sonora and the two peninsular states (Baja California and Baja California Sur [BCS]) are located in the Sonoran Desert Region (Fig. 1). Sonora in particular is rich in both plant and animal biodiversity, as well as endemic species, owing to its location in a transition zone between Nearctic and Neotropical regions of North America (Molina-Freaner & Van Devender 2010, Jones et al. 2013, Holmgren et al. 2014). A variety of other biomes are also present in Sonora, including grasslands, thornscrub, tropical deciduous forest, pine–oak woodland, pine forest, and mixed conifer forest of the Sierra Madre Occidental (Dimmitt 2000, Martínez-Yrízar et al. 2010).

Although knowledge of the overall diversity of insects in Sonora is rudimentary, the biodiversity of butterflies is relatively well known, mainly owing to field work conducted over the last 30 years (reviewed by Bailowitz & Palting 2010). During this period, two species new to science, *Polites norae* (Hesperiidae) (MacNeill 1993) and *Euchloe guaymasensis* (Pieridae) (Opler 1987) were discovered at, or near Guaymas in southern Sonora.

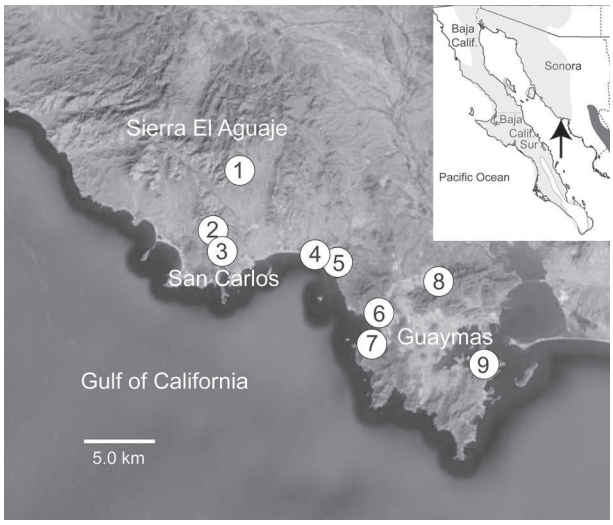

FIG. 1. Map of northwestern Mexico (inset) showing the location of the study area in the Guaymas region of coastal southern Sonora (arrow). Approximate boundaries of the Sonoran Desert (light gray shading) and the northwestern limit of the tropical deciduous forest biome in North America (dark gray shading) are shown on the inset. The Google™ Earth satellite photograph shows the location of the principal study sites. **1**, Cañón de Nacapule; **2**, Sierra El Aguaje foothills; **3**, El Esterito; **4**, Coastal sand dunes; **5**, Estero del Soldado; **6**, Estero de Bacochibampo; **7**, Bahía de Bacochibampo; **8**, Cerro Microondas El Vigía; **9**, Bahía de Guaymas.

Bailowitz and Palting (2010) list a total 338 species for the state of Sonora and predicted that this number will increase with additional field work. Brock (2009) lists 353 species in an online database, and most recently, Llorente-Bousquets et al. (2014) report a total of 257 species, excluding the Hesperiidae. The biodiversity and ecology of species inhabiting or restricted to the coastal environment in Sonora, however, have received little attention, and published information on life histories and ecology of Sonora butterflies in general is scarce. Thus, it is difficult to assess the degree to which the ongoing loss, fragmentation and pollution of the coastal landscape in northwestern Mexico are affecting populations of these insects.

Currently only two butterfly species are officially listed as threatened or protected in Mexico, the well-known migratory monarch, *Danaus plexippus* and *Papilio esperanza* (Beutelspacher 1975) from Oaxaca (Diario Oficial de la Federación 2010, Hernández-Baz et al. 2013). The creation of the Monarch Butterfly Biosphere Reserve by the Mexican government in the year 2000 has been instrumental in reducing illegal logging and protecting the overwintering sites of the monarch in the states of Michoacán and México (Vidal et al. 2014). But as will be shown here, other, less charismatic and often inconspicuous species are also potentially threatened by habitat loss and fragmentation.

To gain an understanding of butterflies that might be particularly threatened by anthropogenic changes in the coastal ecosystem of northwestern Mexico, an inventory of species present in the Guaymas region is presented based mainly on systematic presence data obtained over a 21-month period (November 2013 to July 2015), but also including general observations and collection records dating back to 1978. A discussion then follows of the life history, ecology and population biology of several species that may be the most vulnerable to habitat modification. The rationale used is that threats will be highest for species with poor dispersal capability that are dependent on a single larval host plant growing only, or mainly, in the threatened habitat. Larval host plants for several coastal butterfly species from both Sonora and the Baja California Peninsula are already known from previous studies (Bailowitz 1988, Brown et al. 1992, MacNeill 1993, Pfeiler 2011). Loss of a specific host plant would be predicted to extirpate local populations dependent on that resource, unless affected butterfly species were able to adapt to new, alternative hosts. Although the survey area is relatively small, the species identified as potentially threatened are found throughout coastal Sonora, and most of these are also present in Baja California Sur, thus the butterfly conservation issues raised here should also apply over a broader geographic area of northwestern Mexico.

MATERIALS AND METHODS

Study region. The study region is located in the vicinity of Guaymas, Sonora, Mexico (27°55'30"N, 110°54'20" W), a major commercial port city on the Gulf of California near the southern periphery of the mainland portion of the Sonoran Desert (Fig. 1). Butterfly biodiversity was determined by sampling and monitoring at nine sites within an area of about 50 km^2 (Fig. 1). The sites were located in a variety of habitats (see Fig. 2), including coastal desert mountains (Cañón de Nacapule in the Sierra El Aguaje [site 1], foothills of the Sierra El Aguaje near San Carlos [site 2] and Cerro Microondas El Vigía located immediately behind Guaymas [site 8]), mangrove "esteros" (negative estuaries or hypersaline lagoons with little or no permanent freshwater inflow; El Esterito [site 3], Estero del Soldado [site 5] and Estero de Bacochibampo, also known as Estero Miramar [site 6]), coastal sand dunes and adjacent coastal plains (site 4), and coastal areas with rocky shores (sites 7 and 9).

To the south and east of Guaymas desert thornscrub replaces Sonoran Desert vegetation. In the Guaymas region, the coastal plain immediately behind the sand

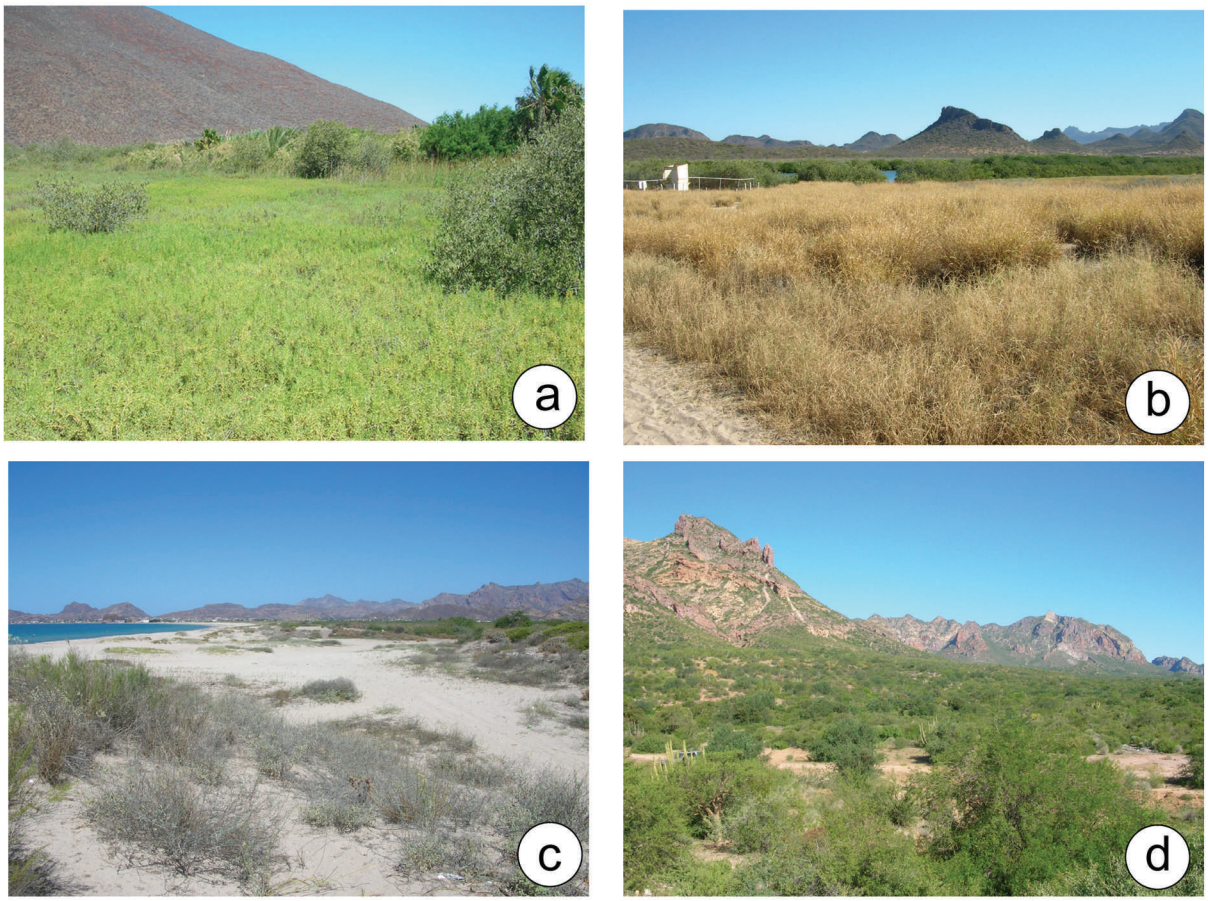

FIG. 2. (**a**) North part of Estero de Bacochibampo (site 6) showing large field of saltwort *Batis maritima*, with southern cattail *Typha domingensis* Pers. (Typhaceae) in the background, and two small black mangrove trees *Avicennia germinans* in the foreground. *Ascia m. monuste* is especially abundant here, flying with smaller numbers of *Junonia genoveva*; (**b**) Buffelgrass (*Pennisetum ciliare*) invasion of coastal sand dunes (foreground) adjacent to mangrove trees at Estero del Soldado (site 5, seen in background); (**c**) Coastal sand dunes (site 4) west of Estero del Soldado. Desert palafox *Palafoxia arida* is an important nectar source on the dunes, attracting large numbers of different species, especially *Danaus gilippus thersippus* in the fall; (**d**) Sierra El Aguaje, north of San Carlos. Cañón de Nacapule (site 1) is in the distant center at the base of mountains.

dunes and extending to the base of the Sierra El Aguaje is comprised primarily of vegetation characteristic of a desertscrub–thornscrub ecotone. Currently, urban sprawl in the Guaymas region is rapidly degrading and fragmenting this habitat, as well as the immediate coastal areas, although much of the vegetation of the rugged desert mountains of the Sierra El Aguaje remains largely unaltered (Felger 1999). The northernmost extent of the tropical deciduous forest biome in western North America occurs approximately 140 km east of Guaymas (Martínez-Yrízar et al. 2010; also see Fig. 1), and tropical elements from this biome enter the protected canyons in the study area, especially at Cañón de Nacapule (Felger 1999). The spring-fed oases of the most accessible lower tropical canyons of the Sierra El Aguaje, especially at Nacapule, are becoming popular local tourist destinations and increased and largely unregulated human use is also threatening the biodiversity of the flora and fauna in these isolated freshwater microhabitats (Bogan et al. 2014).

The climate in the Guaymas region is characterized by generally frost-free winters and high summer temperatures that can exceed 40°C (see Brito-Castillo et al. 2010). Relative humidity during the summer is also high, averaging about 70%, with daily values often exceeding 85%. Rainfall, which is highly variable, averages about 220 mm per year, most of which occurs during the summer and early fall (Durrenberger & Murrieta 1978). The remainder occurs during the winter and spring associated with North Pacific frontal systems, but in many years these winter storms are absent. In the 8-month period from November 2013 through June 2014, only 6 mm of rain was recorded at

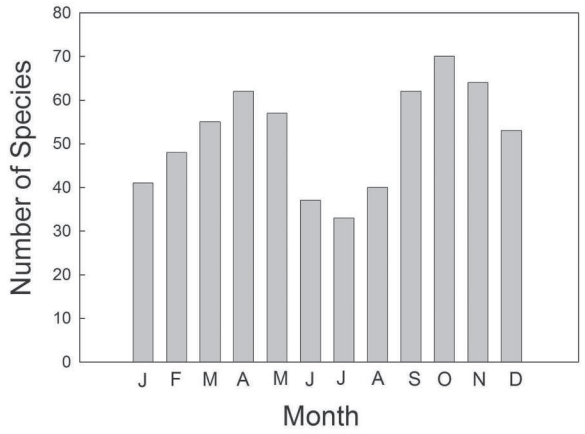

FIG. 3. Total number of butterfly species recorded during each month in the Guaymas region (data from all sites combined) summarized from Table 1.

San Carlos, and only about twice that amount occurred during the same period of 2012/2013 (EP, personal observation). The extreme heat and seasonal drought severely limits most plant life (Felger 1999), which in turn can have profound effects on butterfly abundance by influencing range expansions and contractions (Bailowitz & Palting 2010). Larvae of several species in the Guaymas region, however, feed solely, or mainly on halophytes (see Discussion), and thus their populations appear to be largely independent of the variable annual rainfall.

Butterfly monitoring. Presence data were obtained by systematically monitoring coastal areas deemed to be under the greatest threat of habitat degradation based on current and projected development (sites 3 to 6) from November 2013 to July 2015. Walking surveys lasting about one hour and following approximately the same route on each survey were conducted weekly or biweekly by EP. We also included additional periodic observations and collection records from all sites in the data set, mainly obtained from 2003 to 2012, although some records were from earlier years (1978, 1983–85, 1996 and 1998). A previous study (Pfeiler et al. 2012a) reported on the relative seasonal abundance of the mangrove buckeye *Junonia genoveva* at site 5. Because of the large number of species surveyed here it was not feasible for a single observer to determine seasonal abundance for each one. However, general observations on relative seasonal changes in overall butterfly abundance are mentioned. A recent study (Casner et al. 2014) has shown the usefulness of multi–species presence data, as reported here, in inferring population trends over time. Species records for the Guaymas region also were obtained from the literature and from two excellent websites, the Butterflies of America (Warren et al. 2013) and the Butterflies and Moths of North America (Lotts & Naberhaus 2014).

With minor exception, nomenclature follows Pelham (2008) for species that are also recorded in the USA, and Warren et al. (2013) for those with tropical affinities. In Pelham (2008), the spelling of the original specific epithet is retained and not changed to conform to the gender of the genus name. Common butterfly names follow those given on the Butterflies of America website. Identification of species utilizing this website as a guide was straightforward in most cases. However, two species of the Hesperiidae listed by Brock (2009) for Sonora, *Urbanus procne* (Plötz) and *Achalarus toxeus* (Plötz), are often difficult to distinguish from their congeners in Mexico. To provide support for taxonomic assignments, DNA barcodes were obtained for several specimens tentatively assigned to these species. Methods for extracting DNA from butterfly legs, and for amplifying and sequencing a 658 bp segment of the mitochondrial cytochrome c oxidase subunit I gene (COI) are described elsewhere (Pfeiler et al. 2012b). Comparison of the new COI sequences (accession numbers given below) with reference sequences available in the Barcode of Life Data Systems (BOLD) (Ratnasingham & Hebert, 2007) confirmed our identifications of *U. procne* (GenBank KT290034–KT290036) and *A. toxeus* (KT290038). Names for plants generally follow the Southwest Environmental Information Network (SEINet 2014) or Turner et al. (1995).

RESULTS

Butterfly presence data from the four coastal sites obtained during the intensive survey (2013 to 2015), together with data obtained from all sites in all years, were combined and presented as species observed over monthly intervals (Table 1). A total of 105 butterfly species was recorded over the 38-year period in the Guaymas region, representing about 30% of the 353 butterfly species currently recorded for the state of Sonora by Brock (2009). Of the total, only five species were not recorded along the immediate coast. These include *Agathymus fieldi* (Hesperiidae), a species not personally observed by us but which has been reported for Cañón de Nacapule (site 1) by J. P. Brock (Warren et al. 2013), *Anartia jatrophae luteipicta*, *Microtia elva* and *Texola perse* (Nymphalidae) from site 2, and *Euchloe guaymasensis* (Pieridae) from site 8.

Based on our long-term observations, most species recorded are permanent residents in the study area. In addition, these observations reveal no obvious trends in population increases or decreases in the resident species

over four decades. Several species, however, were only seen once and are considered strays from nearby thornscrub or tropical deciduous forest habitats. These include *Astraptes fulgerator azul* (see footnote to Table 1), *Panoquina ocola ocola*, *Battus polydamas polydamas, Phoebis neocypris virgo, Chlorostrymon simaethis sarita, Smyrna blomfildia, Anartia jatrophae luteipicta, Microtia elva, Anthanassa tulcis* and *Texola perse*. It is possible, however, that *T. perse*, which is quite similar to the abundant *Dymasia dymas chara*, may actually occur more regularly in the region but was overlooked. One tropical species, *Heliconius charithonia vazquezae*, is known to stray widely (Bailowitz & Brock 1991; Cardoso 2010). Single sightings of *H. charithonia vazquezae* occurred in San Carlos in November and December, 1983, March, 1984, and April and November, 1985, but this species has not been seen by us in the survey area since 1985. The migratory monarch *Danaus plexippus plexippus* is occasionally observed (20 confirmed sightings since 2012) from November through February (Table 1).

As mentioned above, it was not feasible for a single observer to obtain systematic abundance data for the large number of species recorded here during the intensive survey. Relative butterfly abundance, however, was highest after the summer rains, usually peaking in October and November, with dramatic decreased abundance evident beginning in early January and lasting throughout the spring and summer to about mid August. Presence data during January to August for many of the species shown in Table 1 were based on sightings of only one or a few individuals, whereas large numbers of many of these same species were seen in the fall. The total number of species observed was highest in October and lowest during July (Fig. 3).

During this study we documented several important nectar sources for butterflies along the coast of Sonora, especially during seasonal drought, including Berlandier's wolfberry *Lycium berlandieri* Dunal (Solanaceae), honey mesquite *Prosopis glandulosa* Torr., coastal sand verbena *Abronia maritima* Nutt. ex S. Watson (Nyctaginaceae), and desert palafox *Palafoxia arida* B.L. Turner & Morris (Asteraceae).

Discussion

Potentially threatened species. Four of the 105 species recorded in the Guaymas region, *Polites norae* (Hesperiidae), *Panoquina errans* (Hesperiidae), *Hypostrymon critola* (Lycaenidae), and *Junonia genoveva* (Nymphalidae) are dependent on specific larval host plants growing in the intertidal zone, or adjacent sand dunes and coastal plains, and thus are considered under the greatest threat owing to coastal habitat degradation. Only Estero del Soldado (site 5), designated as a "Natural Protected Area" administered by the State of Sonora, presently receives partial protection. In addition, three species of mangroves found in the coastal lagoons near Guaymas, black mangrove *Avicennia germinans* (L.) L. (Acanthaceae), red mangrove *Rhizophora mangle* L. (Rhizophoraceae), and white mangrove *Laguncularia racemosa* (L.) Gaertn. f. (Combretaceae) are officially recognized in Mexico as species at risk requiring protection and conservation, and are currently listed as a threatened species (Diario Oficial de la Federación 2003, 2010). Sweet mangrove *Tricerma phyllanthoides* (Benth.) Lundell [= *Maytenus phyllanthoides* Benth.] (Celastraceae), which grows in close association with the other mangroves and on the nearby coastal plains, is abundant and not protected. The principal native grasses (Poaceae) growing in coastal areas are saltgrass *Distichlis spicata* (L.) Greene and shoregrass *Monanthochloe littoralis* Engleman which was recently transferred to the genus *Distichlis* based on molecular studies (Bell & Columbus 2008). To the list of native grasses can now be added the invasive exotic Old World buffelgrass *Pennisetum ciliare* (Fig. 2b). A brief description of the ecology, larval host plant requirements, geographic distribution and taxonomic history of the four potentially threatened butterfly species is given below. Several additional species, either on the periphery of their geographic distribution or of special taxonomic or ecological interest, are also discussed. Photographs of all species listed in Table 1 can be found in Warren et al. (2013).

Polites norae. The Guaymas skipper, *P. norae*, is an inconspicuous species which was recently described from material collected primarily during April 1988 at Bahía de Bacochibampo, Guaymas (MacNeill 1993). The habitat description mentioned the presence of cattails (Typhaceae), which indicates the types were collected at the northern end of Estero de Bacochibampo (site 6; see Figs. 1 and 2a). The larval host plant was presumed to be saltgrass, *Distichlis spicata* (MacNeill 1993), but is now known to be shoregrass *Distichlis littoralis* (J.P. Brock, personal communication; also see Warren et al. 2013). *Polites norae* was never common during the intensive survey, but was seen during most months (Table 1), suggesting at least two broods per year. Adults were found only along the immediate coast at sites 4 and 5 (about 5 km from the type locality) where both *D. littoralis* and *D. spicata* are present. Interestingly, no records for *P. norae* were obtained at the type locality (site 6) or at El Esterito (site 3), sites where *D. littoralis* was absent or at least not easily located.

TABLE 1. Monthly presence records (+) for the 105 butterfly species observed in the Guaymas region.

	MONTH											
	J	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**	**O**	**N**	**D**
HESPERIIDAE												
Eudaminae												
Polygonus leo arizonensis (Skinner)							+					
Chioides albofasciatus (Hewitson)		+	+	+	+	+			+	+	+	+
Chioides zilpa (Butler)		+	+	+	+	+			+	+	+	+
Urbanus proteus proteus (Linnaeus)										+	+	+
Urbanus dorantes dorantes (Stoll)	+							+	+	+	+	+
Urbanus procne (Plötz)					+	+	+			+	+	+
Astraptes fulgerator azul (Reakirt)[a]			+									
Achalarus toxeus (Plötz)	+	+	+	+	+					+	+	+
Cogia hippalus hippalus (W.H. Edwards)				+	+	+	+	+	+	+		
Pyrginae												
Bolla clytius (Godman & Salvin)	+	+	+							+		
Staphylus ceos (W.H. Edwards)			+	+						+		
Pholisora catullus (Fabricius)			+				+	+	+	+		
Timochares ruptifasciata (Plötz)		+	+	+					+	+		
Chiomara georgina georgina (Reakirt)		+		+	+			+	+	+	+	+
Erynnis funeralis (Scudder & Burgess)	+	+	+	+	+	+		+	+	+	+	+
Systasea zampa (W.H. Edwards)	+	+	+	+	+	+			+	+		+
Celotes nessus (W. H. Edwards)							+	+	+			
Pyrgus albescens Plötz		+	+	+	+				+	+	+	+
Heliopyrgus domicella (Erichson)		+		+	+		+		+	+		+
Heliopetes laviana laviana (Hewitson)		+	+	+	+	+		+	+	+	+	
Hesperiinae												
Agathymus fieldi H. Freeman										+		
Ancyloxypha arene (W.H. Edwards)									+	+	+	
Copaeodes aurantiaca (Hewitson)	+	+	+	+	+	+	+		+	+		
Copaeodes minima (W. H. Edwards)					+				+	+		
Panoquina errans (Skinner)	+	+	+	+	+	+	+	+	+	+	+	+
Panoquina ocola ocola (W.H. Edwards)				+								
Amblyscirtes tolteca prenda Evans					+	+	+	+	+	+		
Lerodea eufala eufala (W.H. Edwards)	+	+	+	+	+	+	+	+	+	+	+	+
Lerodea arabus (W.H. Edwards)	+	+	+		+					+	+	+
Lerema accius (J. E. Smith)		+	+								+	
Hylephila phyleus phyleus (Drury)	+	+	+	+	+	+	+	+	+	+	+	+
Polites norae C. MacNeill	+	+	+	+	+	+		+			+	+

TABLE 1. Continued

	MONTH											
	J	F	M	A	M	J	J	A	S	O	N	D
PAPILIONIDAE												
Papilioninae												
Battus philenor philenor (Linnaeus)	+	+		+	+	+	+	+	+	+	+	+
Battus polydamas polydamas (Linnaeus)										+		
Papilio polyxenes asterius (Stoll)		+		+	+	+	+					
Heraclides rumiko Shiraiwa & Grishin			+	+	+	+	+	+	+	+		
PIERIDAE												
Coliadinae												
Kricogonia lyside (Godart)	+	+	+	+	+	+	+	+	+	+	+	+
Nathalis iole Boisduval	+	+	+	+	+				+	+	+	+
Eurema daira sidonia (R. Felder)										+	+	
Eurema boisduvaliana (C. Felder & R. Felder)	+	+	+	+	+	+				+	+	+
Eurema mexicana mexicana (Boisduval)			+	+	+					+	+	+
Pyrisitia proterpia (Fabricius)	+								+	+	+	+
Pyrisitia lisa (Boisduval & Le Conte)		+	+	+	+				+	+	+	
Pyrisitia nise nelphe (R. Felder)	+		+	+	+	+		+	+	+	+	+
Abaeis nicippe (Cramer)	+	+	+	+	+	+	+	+	+	+	+	+
Colias eurytheme Boisduval				+	+		+	+	+		+	
Zerene cesonia cesonia (Stoll)	+	+	+	+	+	+	+	+	+	+	+	+
Anteos clorinde (Godart)									+			
Anteos maerula (Fabricius)							+	+	+		+	
Phoebis sennae marcellina (Cramer)	+	+	+	+	+	+	+	+	+	+	+	+
Phoebis agarithe agarithe (Boisduval)			+	+	+	+	+	+	+	+	+	+
Phoebis philea philea (Linnaeus)									+		+	
Phoebis neocypris virgo (Butler)						No Date						
Pierinae												
Euchloe guaymasensis Opler		+										
Pontia protodice (Boisduval & Le Conte)	+		+	+			+	+	+	+	+	
Ascia monuste monuste (Linnaeus)	+	+	+	+	+	+	+	+	+	+	+	+
Ganyra howarthi (Dixey)	+	+	+	+	+	+	+	+	+	+	+	+

TABLE 1. Continued

	MONTH											
	J	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**	**O**	**N**	**D**
LYCAENIDAE												
Theclinae												
Atlides halesus corcorani Clench			+									
Arawacus jada (Hewitson)				+								
Chlorostrymon simaethis sarita (Skinner)					+							
Strymon melinus franki W.D. Field	+	+	+	+	+	+			+	+	+	
Strymon bebrycia (Hewitson)				+	+					+		+
Strymon bazochii bazochii (Godart)					+							
Strymon istapa istapa (Reakirt)			+	+	+				+	+	+	+
Ministrymon leda (W.H. Edwards)	+			+	+	+			+	+	+	+
Hypostrymon critola (Hewitson)	+	+	+	+	+	+			+	+	+	+
Polyommatinae												
Leptotes marina (Reakirt)		+	+	+	+	+				+	+	
Brephidium exilis exilis (Boisduval)	+	+	+	+	+	+	+	+	+	+	+	+
Hemiargus ceraunus gyas (W.H. Edwards)	+		+	+	+	+	+	+	+	+	+	+
Echinargus isola (Reakirt)			+								+	
RIODINIDAE												
Riodininae												
Calephelis nemesis nemesis (W.H. Edwards)	+	+	+	+	+	+				+	+	+
Calephelis arizonensis McAlpine							+	+	+			
Apodemia mejicanus mejicanus (Behr)				+	+			+	+	+	+	
Apodemia palmerii arizona Austin		+	+	+	+			+	+	+	+	
Apodemia multiplaga Schaus			+						+			
Baeotis zonata zonata Felder		+		+								
NYMPHALIDAE												
Libytheinae												
Libytheana carinenta streckeri Austin & J. Emmel	+	+	+	+	+			+	+	+	+	+
Danainae												
Danaus plexippus plexippus (Linnaeus)	+	+									+	+
Danaus gilippus thersippus (H. Bates)	+	+	+	+	+	+	+	+	+	+	+	+
Danaus eresimus montezuma Talbot											+	+
Heliconiinae												
Agraulis vanillae incarnata (N. Riley)	+	+	+	+	+	+	+	+	+	+	+	+
Heliconius charithonia vazquezae W. Comstock & F. Brown			+	+							+	+
Euptoieta claudia (Cramer)							+					
Euptoieta hegesia meridiania Stichel	+			+	+	+		+	+	+	+	+

TABLE 1. Continued

	MONTH											
	J	F	M	A	M	J	J	A	S	O	N	D
NYMPHALIDAE (continued)												
Apaturinae												
Asterocampa idyja argus (H. Bates)										+		
Biblidinae												
Mestra amymone (Ménétriés)	+								+	+		
Myscelia cyananthe skinneri Mengel	+	+	+	+			+	+	+	+	+	
Hamadryas februa (Hübner)[b]									+			
Hamadryas glauconome grisea Jenkins[b]		+							+	+		+
Nymphalinae												
Smyrna blomfildia (Fabricius)								+				
Vanessa virginiensis (Drury)											+	+
Vanessa cardui (Linnaeus)	+	+	+	+				+	+	+	+	+
Vanessa annabella (W.D. Field)				+	+						+	+
Vanessa atalanta rubria (Fruhstorfer)		+										
Anartia jatrophae luteipicta Fruhstorfer						No Date						
Junonia nigrosuffusa W. Barnes & McDunnough			+							+	+	+
Junonia genoveva (Cramer)	+	+	+	+	+	+	+	+	+	+	+	+
Chlosyne eumeda (Godman & Salvin)	+		+	+	+				+	+	+	+
Chlosyne lacinia crocale (W.H. Edwards)				+					+			
Microtia elva H. Bates						No Date						
Dymasia dymas chara (W.H. Edwards)			+	+			+	+	+	+	+	
Texola perse (W.H. Edwards)					+							
Anthanassa tulcis (H. Bates)												+
Anthanassa texana texana (W.H. Edwards)	+	+	+	+	+	+				+	+	+
Charaxinae												
Anaea aidea (Guérin-Méneville)	+	+		+				+	+	+	+	+

[a] The correct name for this taxon is uncertain as *Astraptes fulgerator* is now considered a complex of species–level taxa (Hebert et al. 2004; Brower, 2010).

[b] *Hamadryas* spp. were observed in April, July, October, November and December, but specimens were not collected and thus could not be confidently identified to species (see Bailowitz & Brock 1991).

MacNeill (1993) had foreseen the potential for habitat degradation at the type locality, and shortly after the types were collected construction of a marina and dredging of Estero de Bacochibampo began. Although most of the lagoon was drastically altered, legal and environmental issues have halted construction for more than 20 years. The mangroves and cattails at the type locality were spared, but enough habitat disruption and loss of larval host plant may have occurred to extirpate the local population of *P. norae*. An extensive area of saltwort *Batis maritima* L. (Bataceae) is now present at this site (Fig. 2a).

Polites norae has been recorded from Puerto Peñasco, Sonora, at the extreme northern end of the Gulf of California (J.P. Brock, personal communication), to Mazatlán, Sinaloa (MacNeill 1993). It was not reported in checklists of butterflies farther south in the states of Jalisco (Vargas et al. 1996) or Colima (Warren et al. 1998), nor is it present on the Baja California Peninsula (Brown et al. 1992, MacNeill 1993). Thus, the distribution of *P. norae* appears to be limited to the narrow coastal strand of northwestern mainland Mexico. Along the coast, near Bachoco in extreme southern Sonora, large stands of *D. littoralis* are found and adults and larvae of *P. norae* were reported to be abundant as recently as the mid-2000s (J.P. Brock, personal communication). But given its restricted distribution and ongoing habitat destruction and loss of host resources, *P. norae* is considered potentially threatened and populations should be monitored.

Panoquina errans. The wandering skipper, *P. errans*, has a wide geographic distribution, found from southern California, USA, the Baja California Peninsula, and mainland Mexico to at least the state of Oaxaca (Warren et al. 2013). But as with the previous species, *P. errans* is restricted to coastal habitats where its host plant *D. spicata* is found (Brown et al. 1992; Pfeiler & Jump 2010). *Panoquina errans* is currently ranked on the IUCN Red List (IUCN 2013) as Lower Risk/near threatened. NatureServe (http:www.natureserve.org) lists *P. errans* as G4G5 (apparently secure or secure globally), but in southern California, at the northern limit of its range, it is listed as S1 (critically imperiled at the state level) owing to the loss of most of its coastal wetland habitat (Speth 1971). Brown et al. (1992) also commented that the continued degradation of coastal salt marshes on the Baja California Peninsula posed a serious threat to this species. In the Guaymas region, *P. errans* was found at coastal sites throughout the year (Table 1) suggesting that the population is healthy. But given its dependence on the threatened coastal habitat the species should be considered potentially at risk.

The fact that *P. errans* is not listed as imperiled at the global level is based on the assumption that the species is panmictic. The possibility of genetic differentiation among geographic populations of *P. errans* throughout its range, however, has not been examined. MacNeill (1962) reported a clinal change in specimens from Santa Barbara, California, USA to the peninsular Cape Region, with southern peninsular specimens from Cabo San Lucas, BCS being slightly larger and darker than those from California. There is also a possibility that disjunct populations from the peninsula and mainland Mexico separated by the Gulf of California may show genetic differentiation similar to that seen in several other species of insects and arachnids (Pfeiler & Markow 2011, Pfeiler et al. 2013). Phenotypic differences between peninsular populations of other butterfly species that also occur on the mainland have resulted in the recognition of several unique peninsular subspecies (MacNeill 1962, Brown et al. 1992). The possibility of genetic differentiation among populations of *P. errans* would have important implications relating to its conservation and management (e.g. McHugh et al. 2013).

Hypostrymon critola. The Sonoran hairstreak, *H. critola*, is found throughout most of the year in the Guaymas region (Table 1), and was especially abundant at site 4 during March, April and December. This species utilizes sweet mangrove (*Tricerma phyllanthoides*) as a larval host in northwestern Mexico (Clench 1975; Brown et al. 1992; Warren et al. 2013), a plant that grows well on wet, saline soils typical of coastal flats of Sonora and Baja California Sur (Turner et al. 1995). Adults are usually found in close association with the host plant. In the Sonoran Desert, however, *H. critola* is also found inland and in southern Mexico (see below), where sweet mangrove is not found, suggesting that other larval hosts may be utilized (Clench 1975, Bailowitz & Brock 1991).

Hypostrymon critola was described by W.C. Hewitson in 1874 (as *Thecla critola*) who listed the type locality only as "Mexico". Historical evidence was later presented indicating that the type locality should be restricted to Guaymas (Clench 1967). In 1891, a very similar species, *H. festata* (Weeks) was described from the Cape Region of the Baja California Peninsula. In subsequent works, Clench (1967, 1975) considered *H. festata* a subspecies of *H. critola*, and in his 1975 paper described two new species from Mexico, *H. margaretae* from Sinaloa and *H. aderces* from Colima and Guerrero. Pelham (2008) considered the names *festata*, *margaretae* and *aderces* junior synonyms of *H. critola*, although possible genetic differentiation among populations has not been studied. Clench (1975) noted that genitalia of all his proposed species in Mexico were

similar. Here we follow Pelham (2008) and recognize a single species, *H. critola*, but it is clear that understanding the phylogeography and systematics of this species also would benefit from molecular genetic studies. It is provisionally listed as potentially threatened in the study area until more information is available on possible alternative host plants.

Junonia genoveva. The mangrove buckeye, *J. genoveva*, is a common inhabitant of mangrove estuaries and adjacent coastal areas of northwestern Mexico, including Baja California Sur (Brown et al. 1992, Pfeiler et al. 2012a). The larval host plant is black mangrove (Pfeiler 2011), thus larvae of *J. genoveva* have a reliable food source that is independent of the highly variable seasonal rainfall in this region. Although previously assigned to *J. evarete* (Cramer) (Brown et al. 1992), or referred to as a hybrid between *J. evarete zonalis* C. Felder & R. Felder and *J. coenia* Hübner (Hafernik 1982), molecular studies suggest that this species should be reassigned, at least provisionally, to *J. genoveva* (Pfeiler et al. 2012b). Although its taxonomy is unstabilized, the ecology and phenology of *J. genoveva* is relatively well known (Pfeiler 2011, 2012a). Adults are on the wing throughout the year (Table 1), but are most abundant during the summer and fall months (Brown et al. 1992, Pfeiler et al. 2012a).

In the Gulf of California, most of the mangrove estuaries have been modified for aquaculture, although these farms are mainly located in sections of the estuaries not occupied by the mangroves (DeWalt et al. 2002, Glenn et al. 2006). However, the long–term ecological effects of secondary impacts of aquaculture on the mangrove ecosystem, such as discharge of nutrients and organic matter (Páez-Osuna et al. 1997, 1998) and the removal of associated coastal flora during construction of the facilities, are unknown. Worldwide, the mangrove forest ecosystem is also highly threatened, primarily owing to aquaculture and tourism developments (Aburto-Oropeza et al. 2008). Because available life history information suggests that populations of *J. genoveva* in northwestern Mexico are restricted to a single threatened larval host plant (Pfeiler 2011), the butterfly also should be considered as potentially threatened.

Additional species of interest. The great southern white, *Ascia monuste monuste* (Pieridae), is a common resident throughout the year in coastal regions of Sonora (Table 1), being especially abundant in the intertidal zone of mangrove estuaries and sand dunes where saltwort *Batis maritima* occurs, its principal larval host plant in northwestern Mexico (Brown et al. 1992). The subspecies, *A. m. raza* Klots is found in coastal areas of the southern half of the Baja California Peninsula and offshore gulf islands (Brown et al. 1992). Although larvae of *A. m. monuste* are polyphagous (DeVries 1987, Janzen & Hallwachs 2009), and the butterfly is widely distributed (southwestern USA to northern South America) and secure globally (ranked G5), we include it here as a species of interest because the principal saltwort host occurs in the region most threatened by development.

Howarth's white, *Ganyra howarthi* (Pieridae), is also a common inhabitant of the survey area often found closely associated with its larval foodplant, desert caper *Atamisquea emarginata* Miers (Capparaceae) (Bailowitz 1988). The foodplant is found throughout much of the Sonoran Desert, including the states of Sonora, Baja California Sur, and southern Baja California, showing a preference for gravelly or sandy plains in maritime climates, but can also be found inland (Turner et al. 1995, SEINet 2014). Distribution records for *G. howarthi* generally reflect the maritime distribution of the larval foodplant (Bailowitz 1988, Brown et al. 1992, Turner et al. 1995), although the butterfly also occurs inland and is known to stray to southeastern Arizona (Bailowitz & Brock 1991). The southernmost verified record is Los Mochis in northern Sinaloa (Bailowitz 1988). As on the Baja California Peninsula (Brown et al. 1992), *G. howarthi* is multiple brooded in the survey region and adults can usually be found throughout the year (Table 1).

The spelling and location of the type locality of *G. howarthi* deserve special mention. The species was originally described as *Pieris howarthi* by Dixey (1915) from specimens collected by Osbert H. Howarth at Tembabichi Bay in Lower California [Baja California Sur, Mexico]. This locality is now listed as "Timbabichi" (INEGI 2014)], but other spellings (e.g. "Tambobiche" and "Tambibiche") are found on maps and navigation charts. Although the latitude of the type locality was originally listed as 26°05' N (Dixey 1915), this latitude is probably an error as the geographic coordinates of Timbabichi on the Gulf coast of the peninsula are 25°16' N, 110°57' W) (INEGI 2014; Google™ Earth [labeled "Tambobiche"]). Desert caper occurs on several of the Midriff Islands in the upper Gulf of California (Turner et al. 1995; SEINet 2014) and given that *G. howarthi* is a relatively strong flier, it is generally assumed that the peninsular and mainland populations are panmictic. But genetic confirmation for the lack of population structure and genetic diversification is lacking. A name is available for the mainland population (Bailowitz 1988) if it is ultimately shown to be genetically distinct from the peninsular population.

Although presently not considered at risk, the Sonoran marble, *Euchloe guaymasensis* (Pieridae), is

also a species of interest because of its relatively recent discovery near Guaymas (Opler 1987). The species is widespread in Sonora (Holland 1995), and given its distribution that includes mountain regions with limited access, the species would appear to be secure. As mentioned earlier, *E. guaymasensis* was found only at site 8 at an altitude of about 215 m where its reported larval host plants, western tansymustard *Descurainia pinnata* (Walt.) Britt. (Brassicaceae) (Holland 1995) and rockmustard *Dryopetalum runcinatum* A. Gray (Brassicaceae) (Back et al. 2011) are found. Both host plants are recorded from the Sierra El Aguaje (SEINet 2014) and additional field work during the main flight period (January to March) may reveal the occurrence of the butterfly there as well. Of concern, however, is that buffelgrass appears to be crowding out the native larval foodplants of *E. guaymasensis* in some areas (J.P. Brock, personal communication).

Species occurring at or near the geographic limits of their range can potentially offer important insight into the relative importance of ecological, environmental, and anthropogenic factors that impact population range expansions and declines (Pfeiler 2013). The narrow-winged metalmark, *Apodemia multiplaga* (Riodinidae), was recorded on the coastal sand dunes, but apparently is near the northwestern limit of its distribution and is quite sporadic in its occurrence. In late March 1998, *A. multiplaga* was relatively abundant on the dunes near San Carlos (J.P. Brock, personal communication), but there have been no subsequent reports until 2014 (present study) when four adults (mid- to late March), and one adult (mid-September), were found feeding on flowers of desert palafox at site 4. The species is widely distributed throughout central and southern Mexico in both coastal and inland regions (Warren et al. 1998, UNIBIO 2014), and is found as far south as northwestern Costa Rica in tropical deciduous forest (DeVries 1997). It has not been reported from the Baja California Peninsula (Brown et al. 1992). Although *A. multiplaga* was described more than a century ago (Schaus 1902), the early stages and larval host plant(s) have not been reported (DeVries 1997). Thus, it is unknown whether the species breeds in the study region, but because it is only rarely seen here it is included as a species of interest that may be threatened by coastal development. It is also possible, however, that the scarcity of sightings is a result of seasonal fluctuations in abundance of a species on the periphery of its distribution (Bossart & Carlton 2002).

The mottled sootywing, *Bolla clytius* (Hesperiidae), is another widespread species, occurring from northern Mexico to Honduras, with rare strays recorded for southeastern Arizona and southern Texas (Bailowitz & Brock 1991; Warren et al. 2013). It has not been reported from the Baja California Peninsula (Brown et al. 1992). Although apparently common in tropical deciduous forest and thornscrub habitat in Sonora (Bailowitz & Brock 1991; Glassberg 2001), it is also a species which is near the northwestern limits of its distribution and apparently is not common in the study region. Only five adults were recorded, one in October 2010 at San Carlos, and four at site 4 from January to March, 2014 feeding on flowers of Berlandier's wolfberry. As with *A. multiplaga*, the larval host plant of *B. clytius* has not been reported, and the butterfly is also listed as a species of interest.

Conservation prospects. A thorough understanding of regional biodiversity is essential before conservation measures can be considered on taxa of interest in the face of landscape conversion and fragmentation. The present study provides the first comprehensive baseline data on species richness of the butterfly fauna in coastal southern Sonora, a region currently undergoing rapid and extensive landscape transformation. We focused on the butterflies because they are relatively easy to identify and monitor. The conservation issues raised here, however, obviously apply to invertebrates in general, terrestrial and aquatic, dependent on the coastal habitat in northwestern Mexico.

In addition to an inventory documenting species richness, knowledge of the ecology of potentially threatened species is crucial to predicting what the overall impact of landscape transformation might have on survival of the species in question. Previous studies cited above have documented the specific host plant requirements of *Polites norae, Panoquina errans, Hypostrymon critola* and *Junonia genoveva*. Knowing that each species requires a specific larval host plant largely restricted to coastal habitats allowed us to predict that these four species are potentially the most vulnerable to habitat degradation. The continued fragmentation and loss of the natural vegetation in this region is highly probable given that the land is privately owned and designated for development. Although there is little prospect of setting aside and preserving the sand dunes and coastal plains near Guaymas, the Mexican government has specified a large tract of coastal habitat in extreme southern Sonora as a "priority area" for protection (Arriaga et al. 2000). It is unknown whether the "priority area" will ultimately receive official protected status, but the four species of butterflies we identified as potentially threatened, and their larval host plants, are present there.

Note added in proof. A single individual of *Ministrymon clytie* (W.H. Edwards), a species not previously observed by us in the study region, was

photographed by EP at site 4 on 24 October 2015, thus bringing the total number of species to 106. Also, a single individual of *Anartia jatrophae luteipicta* Fruhstorfer (Table 1) was seen at site 1 on 29 October 2015, providing an additional record and confirmed date for this species. Site 1 has recently been added to the list of "Natural Protected Areas" by the State of Sonora.

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