

Biodiversity in the Madrean Archipelago of Sonora, Mexico

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Introduction

Flowery rhetoric often gives birth to new terms that convey images and concepts, lead to inspiration and initiative. On the 1892-1894 expedition to resurvey the United States-Mexico boundary, Lieutenant David Dubose Gaillard described the Arizona-Sonora borderlands as “*bare, jagged mountains rising out of the plains like islands from the sea*” (Mearns 1907; Hunt and Anderson 2002). Later Gaillard was the lead engineer on the Panama Canal construction project.

In 1951, Weldon Heald, a resident of the Chiricahua Mountains, coined the term ‘Sky Islands’ for the ranges in southeastern Arizona (Heald 1951). Frederick H. Gehlbach’s 1981 book, *Mountain Islands and Desert Seas: A Natural History of the US-Mexican Borderlands*, provided an overview of the natural history of the Sky Islands in the southwestern United States. The ‘desert seas’ in the valleys are desert grassland and Chihuahuan desertscrub in the north, Sonoran desertscrub to the west, and foothills thornscrub in the south. Variants of the term include Sky Island region (McLaughlin 1995; Gottfried and others 2005; Skroch 2008), sky-island ranges (Felger and Wilson 1995; Fishbein and others 1995), and sky island bioregion (Fishbein and others 1995; Skroch 2008). Today we mostly use ‘Sky Island Region’ with capital letters. The best name in Spanish is *Islas Serranas*, rather than the literal translation *Islas del Cielo*, because *cielo* means both ‘sky’ and ‘heaven.’ The analogy to oceanic islands (Warshall 1995) is limited because Sky Islands differ from true insular areas in high species diversity, low local and regional endemism, and low percentages of non-native species (McLaughlin 1995). While any isolated area is a potential area for speciation in small populations, there are relatively few species restricted to the Sky Island Mountains.

The term ‘Madrean’ comes from the Sierra Madre. The Mexican Plateau is a vast area of grasslands and desertscrub between the Rocky Mountains in New Mexico and ca. 1,300 km to the south the Trans-Mexican Volcanic Belt in south-central Mexico. The Plateau is

open to incursions of frigid Arctic air from the north, and the Sierra Madres Oriental and Occidental create a double rain shadow and the Chihuahuan Desert. Madrean is a general term used to describe things related to the Sierra Madres. In a biogeographical analysis of the herpetofauna of Saguaro National Monument, University of Arizona herpetologist and ecologist Charles H. Lowe was probably the first to use the term ‘Madrean Archipelago’ to describe the Sky Island ranges between the Sierra Madre Occidental in Sonora and Chihuahua and the Mogollon Rim of central Arizona (Lowe, 1992). Warshall (1995) and McLaughlin (1995) expanded and defined the area and concept.

Biodiversity

In 2007, Conservation International named the Madrean Pine-oak Woodlands as a global biodiversity hotspot. This was a very large area that included the Sierra Madre Oriental in eastern Mexico, the Sierra Madre Occidental (SMO) in western Mexico, and the Sky Island ranges north of them into Texas, New Mexico, and Arizona. The Sierra Madre Occidental extends in western Mexico from Zacatecas and Jalisco north to Chihuahua and Sonora. The southwestern United States is famous for its diversity of animals and plants, and in many groups diversity increases southward in Sonora into the Sierra Madre Occidental and the New World tropics.

Species richness is enhanced in the Sky Island Region for many reasons. The western half of North America is mountainous, with topographically diverse habitats and vegetation zoned along elevational-climatic gradients. Biotic communities are concentrated in small geographic areas compared to the eastern United States where vegetation mostly changes along a north-south latitudinal gradient.

The Madrean Archipelago is a convergence zone for five biotic provinces (fig. 1). The Rocky Mountains and Colorado Plateaus to the north have temperate climates. In the mid-continent, the grasslands of the Great Plains extend from Canada south to New Mexico, Texas, and the Mexican Plateau. In the south, a mosaic with desert grassland in the valleys and Chihuahuan desertscrub on adjacent limestone slopes extends westward into southeastern Arizona and northeastern Sonora. On the western edge of the Sky Island Region, Sonoran desertscrub surrounds Sky Island ranges. In the south, more tropical oak woodlands and pine-oak forests are in the Sierra Madre Occidental and Sky Island mountaintops. In the lowlands, foothills thornscrub (FTS) and tropical deciduous forest are present. The transition between the New World tropics and the northern temperate zone is at about 29°N in

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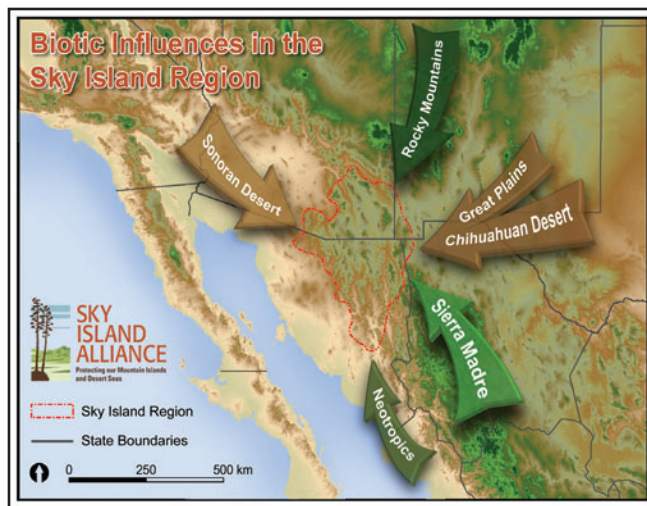


Figure 1—Map of the biotic convergence in the Madrean Archipelago (map by Nick Deyo).

east-central Sonora. The northern limits of FTS in Sonora are at about 30°11'N east of Sinoquipe in the Río Sonora Valley and 30°26'N at Presa Angostura on the Río Bavispe at the southern end of the Sierra El Tigre. FTS does not reach Arizona, but the distributions of quite a few FTS species cross the border into southern Arizona in desert grassland or oak woodland.

Sky Island Bioblitzes

Today the term 'bioblitz' is popular, meaning an intensive effort in a short period to document the diversity of animals and plants in an area. The first bioblitz in the southwestern United States was the 1848-1855 survey of the new boundary between the United States and Mexico after the Treaty of Guadalupe Hidalgo of 1848 ended the Mexican-American War. The border between El Paso, Texas, and the Colorado River in Arizona was surveyed in 1855-1856, following the Gadsden Purchase in 1853. Besides surveying and marking the border with monuments, these expeditions made extensive animal and plant collections, often by army physicians. Botanists John M. Bigelow, Charles C. Parry, Arthur C. V. Schott, Edmund K. Smith, George Thurber, and Charles Wright (fig. 2) and zoologist John H. Clark collected between the Santa Rita Copper Mines (= Silver City), New Mexico and Santa Cruz, Sonora in the modern Arizona-Sonora borderlands. On the second United States-Mexico Boundary Survey in 1892-1894, Edgar A. Mearns (fig. 3) collected 30,000 animal and plant specimens. The mammals were published in the book *Mammals of the Mexican Boundary of the United States* (Mearns 1907). In 1890, Norwegian Carl S. Lumholtz led an anthropological expedition through northeastern Sonora. He published a popular travelogue in 1902. Sweden's Carl V. Hartman was a botanist in charge of general biological collections (fig. 4).

Río Mayo-Yécora Baseline

In the 1930s, Howard Scott Gentry was a recent graduate from the University of California at Berkeley. In search of employment, he went to the New World tropics in the Álamos area in southern Sonora, in hopes of selling biological specimens to museum collections. His

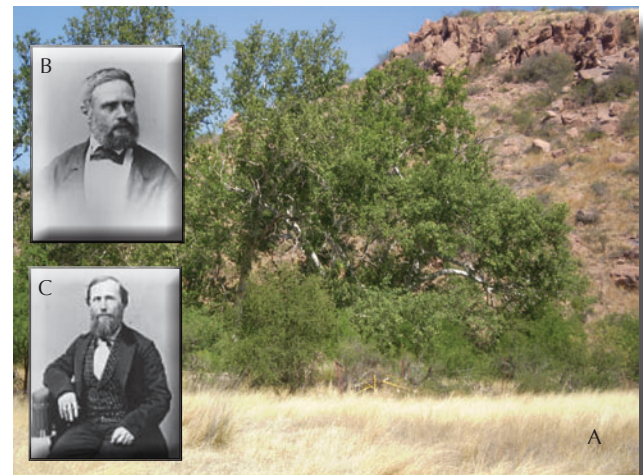


Figure 2—(A) The U.S.-Mexico Boundary and Gadsden Purchase Surveys of 1848-1857 went through Guadalupe Canyon (photo by T. R. Van Devender). (B) Arthur C.V. Schott and (C) Charles Wright were expedition botanists.



Figure 3—(A) The second U.S.-Mexico Boundary Survey in 1892-1894 was led by Edgar A. Mearns. (B) The Arizona-Sonora Boundary is between the Sierra San José and the Huachuca Mountains (photo by T. R. Van Devender).

plant collections were published in the book *Río Mayo Plants* (Gentry 1942). In the 1970s, 80s, and 90s, Paul S. Martin led expeditions from the University of Arizona, which retraced Gentry's travels, explored new areas, and resulted in a revision of the Río Mayo flora (Martin and others 1998). This large area includes the Sierra Madre Occidental in eastern Sonora and western Chihuahua.

Studies of the flora and fauna of the Yécora area in the SMO in eastern Sonora provide baseline information needed to compare biotas in the Madrean Archipelago with the mainland Sierra Madre Occidental, putting the biodiversity of Sky Island ranges in regional context. Mexican Federal Highway 16 (MEX 16), one of the few highways that crosses the SMO, provides a west-to-east elevational transect from the Río Yaqui (180 m) east to the Chihuahua border, 42 km east of Yécora (fig. 5).

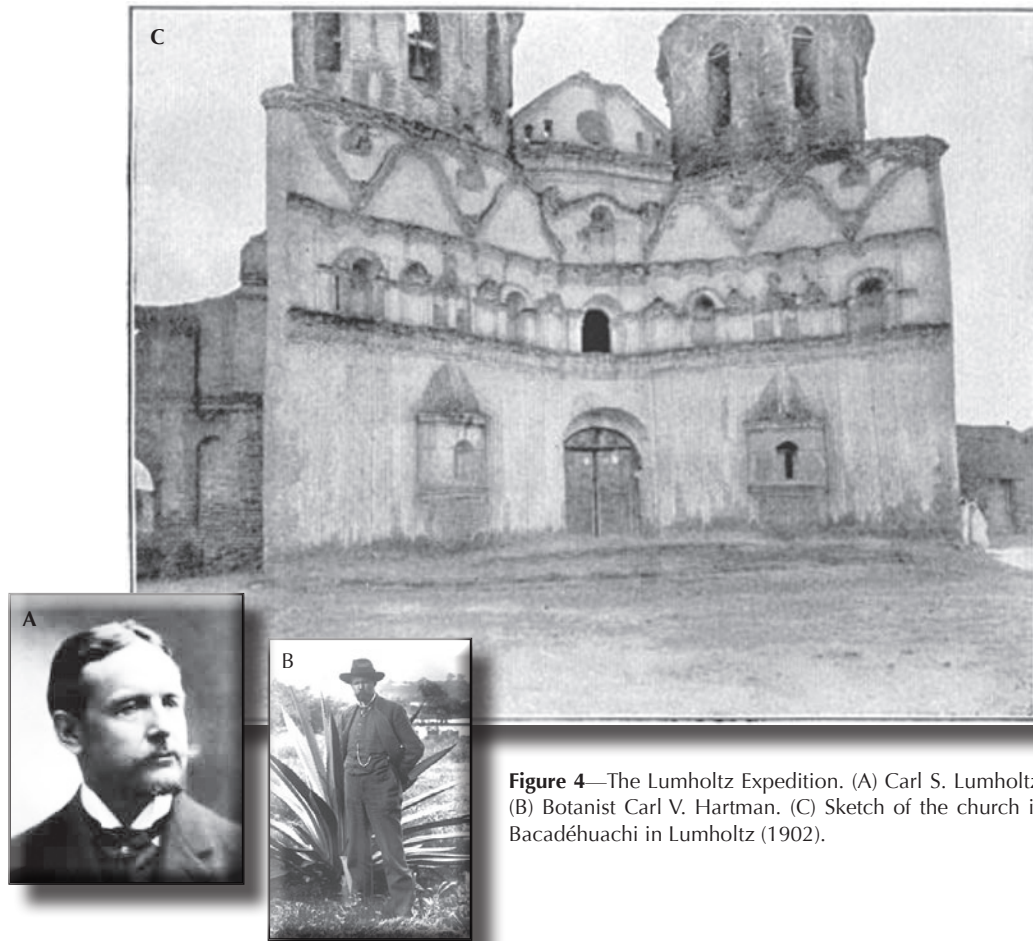


Figure 4—The Lumholtz Expedition. (A) Carl S. Lumholtz. (B) Botanist Carl V. Hartman. (C) Sketch of the church in Bacadéhuachi in Lumholtz (1902).



Figure 5—Sunset in the Sierra Madre Occidental west of Yécora, Sonora (photo by Erik F. Enderson).

Between 1953 and 2005, herpetologist-ecologist Charles H. Lowe collected amphibians and reptiles in the Yécora area for the University of Arizona Herpetological Collection on 33 trips involving 26 people. From 2004 to 2008, Erik F. Enderson and Robert L. Bezy documented the Yécora area herpetofauna through photography on 40 field days. Van Devender and Ana L. Reina-Guerrero at the Arizona-Sonora Desert Museum (ASDM) studied the flora of the Municipio

de Yécora region on 36 fieldtrips from 1995 to 2008. This flora with 1,776 taxa in 3,300 km² is very diverse, ca. 30% more diverse than the Huachuca Mountains in southeastern Arizona (Reina-G. and Van Devender 2005). There are 2,125 observations of 301 species of birds from the Municipio de Yécora in the Madrean Archipelago Biodiversity Assessment (MABA) database (<http://www.Madrean.org>).

Borderlands Exploration

Higher Sky Island mountain ranges such as the Sierras de los Ajos, Elenita, Marquita, and Tigre have extensive pine-oak forest and mixed-conifer forests on the highest peaks (fig. 6; Marshall 1957). The biotas of these areas are temperate mixtures of Sierra Madrean and Rocky Mountain species.

In the 1930s and 1940s, the University of Michigan had a very active biological exploration program in Mexico. In 1935, Barry Campbell collected amphibians and reptiles in the Sierra el Tigre, Sonora. From 1938-1941, Stephen S. White led three botanical expeditions to explore the Río Bavispe region of northeastern Sonora (fig. 7). The Río Bavispe flora with 1200 species (currently 995 taxa after revision) in 549 genera in 114 families from a wide range of habitats in the region was the first modern flora in the Sonoran borderlands (White 1948).

Ornithologist and intrepid explorer Joe T. Marshall studied the birds and dominant plants of pine-oak woodland in mountain ranges in southeastern Arizona, northeastern Sonora, and in the northern Sierra Madre Occidental in Chihuahua in the summers of 1951-1953

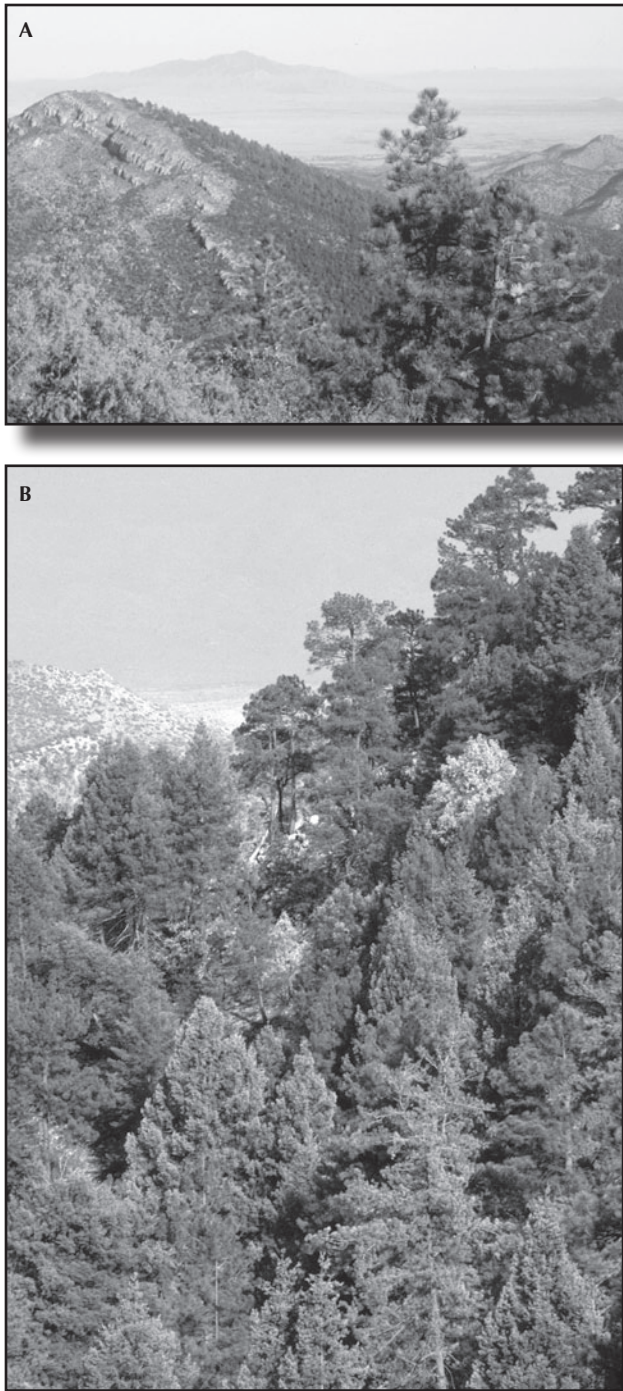


Figure 6—(A) View from the Sierra de los Ajos (photo by Dale S. Turner). (B) Mixed-conifer forest in Sierra El Tigre (photo by George M. Ferguson).

(Marshall, 1957). In Sonora, he worked in the Sierras Aconchi, Azul, “Cananea” (= Elenita-Mariquita), Oposura (= La Madera), and Pinitos.

Beginning in 1963, Raymond M. Turner, J. Rodney Hastings and later Tony L. Burgess made numerous trips to Sonora and Baja, California, to document the distributions of 414 species of plants in the Sonoran Desert. Their observations, collections, and ecological summaries were included in the book *Sonoran Desert Plants. An Ecological Atlas* (Turner and others 1995).



Figure 7—Stephen S. White and José Vera-Santos in the Sierra El Tigre on 13 October 1941.

Beginning in 1964, Stephen M. Russell and Gale Monson went to Sonora to observe birds on 150 trips and 692 field days. Their observations of 525 species were published in the book *The Birds of Sonora* (Russell and Monson 1998). Beginning in 2000, Aaron D. Flesch expanded on their field observations in northern Sonora (Flesch 2008).

In the 1980s and 1990s, the United States Fish and Wildlife Service, Área Natural Protegida (ANP) Ajos-Bavispe (a Comisión Nacional de Áreas Naturales Protegidas [CONANP] reserve), University of Arizona, and The Nature Conservancy Plant Collections organized expeditions to the Sierra de los Ajos just east of Cananea: Frank W. Reichenbacher in 1982, Paul S. Martin in 1983 and 1991, Peter Warren and Esther Saucedo in 1989, and Richard S. Felger, Mark Fishbein, George M. Ferguson, Dale S. Turner, James Malusa, Florentino Garza-S., and Martín Haro in October 1992 and July 1993 (Fishbein and others 1995). Turner, Garza-S., and Haro returned on a zoological expedition in 1998 along with Cecil Schwalbe, Taylor Edwards, Carl Olson, Yar Petryszyn, Dave Prival, and others (Alberti and others 1998).

With a few exceptions, documentation of animals and plants in the Arizona-Sonora borderlands was mostly neglected after the 1848-1857 and 1892-1894 boundary surveys. Even common, widespread species had not been collected or observed. Beginning in 2001, Van Devender and Reina-Guerrero (2005) began collecting and observing plants in *La Frontera*, the area in northern Sonora within 100 km of the Arizona border, as part of several inventory projects.

Leonardo Varela-Espinosa and Alberto Búrquez-Montijo at the Universidad Nacional Autónoma de México in Hermosillo studied the flora of the Sierra San Javier on seven trips from July 1996 to May 1997 (Varela-Espinosa 2005). The Sierra San Javier is the southernmost Sky Island with tropical deciduous forest below oak woodland.

Since 1994, Herbario Universidad de Sonora (USON) has grown into a major regional collection. In 2003-2004, Curator J. Jesús Sánchez-Escalante, Manuel Espericueta-Betancourt, and Reyna A. Castillo-Gómez from USON, and Van Devender and Reina-Guerrero at ASDM studied the flora of the Sierra de Mazatán (Sánchez-Escalante and

others 2005). This range is the southwestern-most Sky Island located 70 km east of Hermosillo in central Sonora. Between March 2009 and September 2011, Sánchez-Escalante, Denise Z. Ávila-Jiménez, David A. Delgado-Zamora, and Liliana Armenta-Cota from USON, and Van Devender and Reina-Guerrero at Sky Island Alliance studied the flora of Rancho El Aribabi in the Sierra Azul on seven field trips. El Aribabi Conservation Ranch in the Sierra Azul was designated an Área Natural Protegida Privada by CONANP in March 2011.

In July–August 2005, biologists from the University of Arizona and the Sonoran Desert Research Station inventoried the fauna and flora along the Río Áros, a tributary of the Río Yaqui in east-central Sonora (O'Brien and others 2006). Participants included Charles O'Brien, Aaron D. Flesch, Eric Wallace, Michael D. Bogan, Samia Carrillo-Percástegui, Sky Jacobs, and Charles van Riper III.

In April–May 2008, Sky Island Alliance organized an expedition to the Sierra El Tigre to observe plants and animals (Avila-Villegas and Jacobs 2008). Participants were Sergio Avila-Villegas, Paul Condon, Sky Jacobs, Matt Skroch, Robert Villa, Rodolfo Villa, and landowners.

Madrean Archipelago Conferences

As recently as two decades ago, few people knew of the Madrean Archipelago as a distinct region and the evidence for its importance was scattered among many disciplines in two countries. In September 1994, a conference entitled *Biodiversity and Management of the Madrean archipelago: The Sky Islands of Southwestern United States and Northwestern Mexico* was organized by the Rocky Mountain Forest and Range Experiment Station, U.S. Forest Service, along with Sky Island Alliance (DeBano and others 1995). There were 69 presentations and 20 posters. The second Madrean Archipelago Conference in May 2004 was entitled *Connecting Mountain Islands and Desert Seas: Biodiversity and Management of the Madrean Archipelago*. There were 93 presentations and 14 posters. The lack of information from the Sky Island Region in Mexico was noted in both conferences.

In May 2012, the third Madrean Archipelago conference assembled the current state of our knowledge about the unique natural and cultural resources of the Madrean region and continued the discussion of management practices useful for maintaining those resources with 24 sponsoring organizations. It brought together researchers, partners in resource stewardship, land managers, educators and students, government officials, consultants, and the interested public from both sides of the border to examine the Madrean Archipelago of the southwestern United States and northwestern Mexico. There were 151 presentations and posters, including substantial advances in the knowledge of animal and plant distributions in Mexico.

Madrean Archipelago Biodiversity Assessment

One of the conclusions of both of the Madrean conferences was that there was an urgent need for information from the Mexican portion of the Sky Island Region. Sky Island Alliance was a principal organizer for both of these conferences. In spring 2009, the Northern Mexico Conservation Program at SIA initiated the Madrean Archipelago Biodiversity Assessment (MABA) project, in part funded by a grant from the Veolia Environment Foundation. The concept of documenting all plant and animal species in the Mexican Sky Island Region for use in conservation, land management, research, and education was proposed by former SIA Executive Director Matt Skroch, Dale Turner, and Aaron D. Flesch.

The online MABA database (<http://www.madrealn.org>) was created to make observations and images available to the public. The FLORA half of the database is directly linked to the Southwestern Environmental Information Network (SEINet) database, which has data for over 2 million herbarium specimens. The FAUNA half of the database was a new database. The MABA database differs from SEINet in that many records are observations rather than specimens, and that observations are often illustrated with color images. Historical records are from museum collections, literature, field notes and other databases. New observations are made on fieldtrips to remote high diversity Sky Island ranges. Study areas were selected based on the need for biological observations, conservation initiatives, and opportunities to collaborate with landowners, land managers, and local researchers.

While observations are made on all MABA trips, expeditions to high priority areas with 25–45 participants are especially productive. These are unprecedented groups of animal and plant specialists, landowners, agency biologists, university professors and students, journalists, photographers, and volunteers (fig. 8). In 2009–2011, there were five MABA Expeditions. In September 2009, 17 participants went to the Sierra San Luis on Cuenca Los Ojos Foundation property. In March 2010, 25 participants went to the Sierra El Tigre on private ranches within the ANPAjos-Bavispe. In August 2010, 39 participants, including professors and students from the nearby Universidad de la Sierra (UNISIERRA), went to the Sierra La Madera on private ranches, partially within the ANPAjos-Bavispe. In April–May 2011, 40 participants went to the Ciénega de Saracachi and the Sierra San Antonio. The Ciénega is an important wetland natural area on Rancho Agua Fría that was proposed as an Área Natural Protegida Estatal by the Comisión de Ecología y Desarrollo Sustentable del Estado de Sonora (CEDES) in 2010. The Sierra San Antonio is privately owned. In August 2011, 45 participants went to the Sierra Bacadéhuachi, which is mostly privately owned. Rincón de Guadalupe, owned by the Catholic Diocese of Hermosillo, has excellent potential for protection as a natural area.

The MABA database is the primary source of biological records for the state of Sonora. FLORA contains 112,623 Sonoran observations, including 20,606 from MABA, 20,331 from the book *Sonoran Desert Plants. An Ecological Atlas* (Turner and others 1995), and 13,285 from the Comisión para el Uso y Conocimiento de la Biodiversidad (CONABIO). FAUNA contains 128,843 Sonoran records, including 60,856 from MABA, 39,022 from the book *The Birds of Sonora* (Russell and Monson, 1998), 33,993 from the eBird database, and 27,404 from CONABIO. Species numbers in the MABA database provide preliminary diversity estimates for the Madrean Archipelago in Sonora. There are ca. 2880 plant taxa in northeastern Sonora. Insects are very diverse, but only 1380 taxa are documented in the Sky Islands Region. Vertebrates are better represented: fish (39 species), amphibians and reptiles (104 species), birds (358 species), and mammals (76 species). Surprisingly, diversity appears to decrease southward, but it probably reflects the north-northwest to south-southeast orientation of the ranges, and decreasing area and fewer biological inventories to the south.

Conclusions

The MABA project has pulled together information from biological expeditions in the Madrean Archipelago from the last 160 years. The knowledge of plant and animal distributions has increased dramatically since 1950, reflecting fieldwork by American botanists, herpetologists, ornithologists, and mammalogists, the development of biology programs at the Universidades de Sonora and de la Sierra,



Figure 8—MABA group at Rincón de Guadalupe in the Sierra Bacadéhuachi in August 2011 (photo by Chris Marzonie).

the CONABIO national biodiversity database, and the Sonoran state Área Naturales Protegidas program by CEDES. The 2010 book *Diversidad Biológica de Sonora*, edited by Francisco Molina-Freaner and Van Devender, summarized the state of knowledge of plants, animals, and vegetation in Sonora. These accomplishments are only the beginning—the opportunities for additional natural history studies in the Madrean Archipelago are enormous!

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Marshall, Edgar Mearns, John Lemmon, John Bartlett, and William H. Emory walked the biodiversity path long before us.

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