Amphibian Alliance for Zero Extinction Sites in Chiapas and Oaxaca

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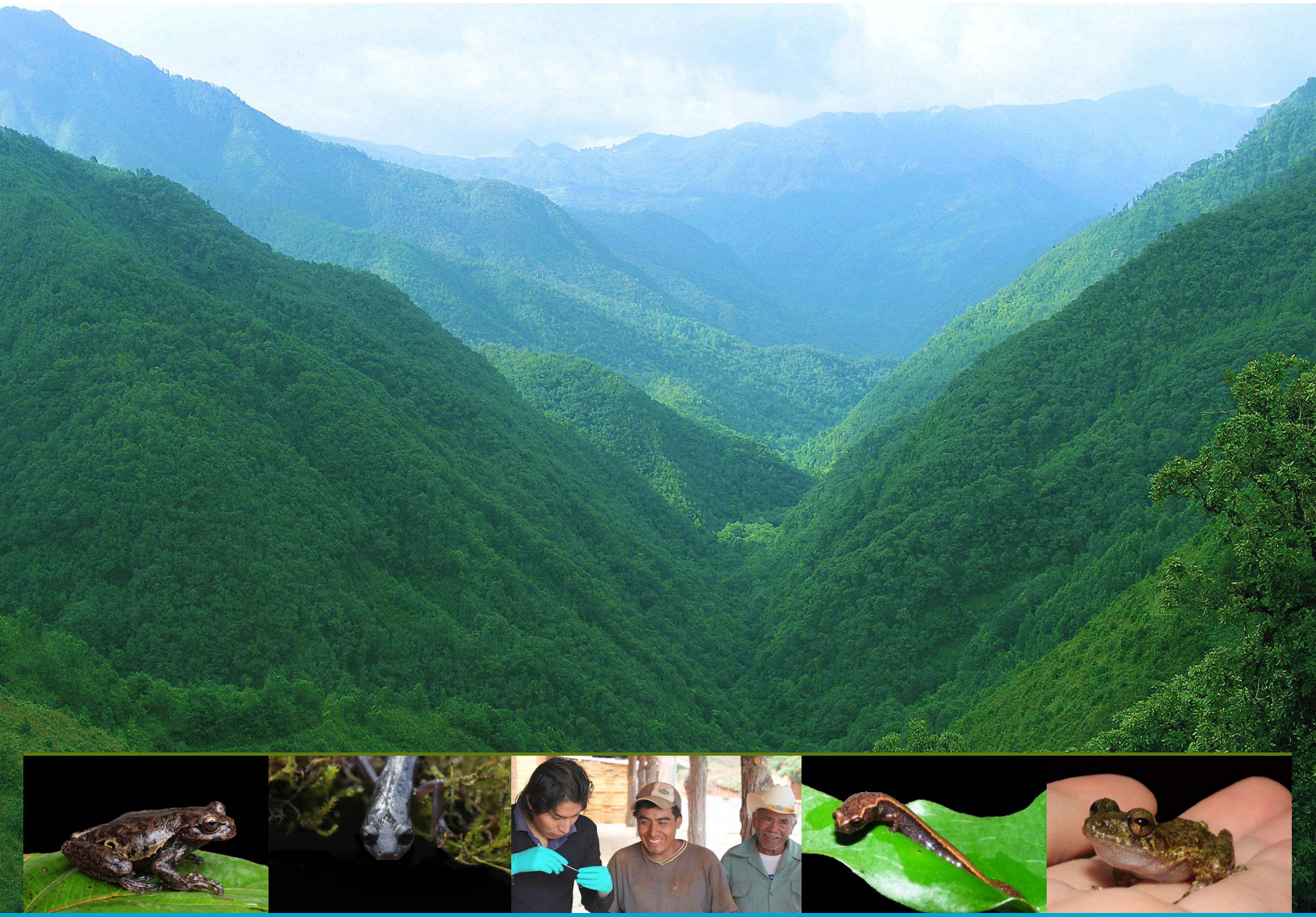

Occasional Paper of the IUCN Species Survival Commission No. 53

SSC Species Survival Commission

ASG IUCN SSC Amphibian Specialist Group

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Cover photographs: Totontepec landscape; new *Plectrohyla* species, *Ixalotriton niger*, Concepción Pápalo, *Thorius minutissimus*, *Craugastor pozo* (panels, left to right)

Back cover photograph: Collecting in Chamula, Chiapas

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The **Species Survival Commission (SSC)** is one of six volunteer commissions of IUCN. SSC's mission is to conserve biological diversity by developing and executing programs to save, restore and wisely manage species and their habitats.

The **Amphibian Specialist Group (ASG)** provides the scientific foundation to inform effective amphibian conservation action around the world. More specifically, the ASG stimulates, develops and conducts scientific research to inform the conservation of amphibians and their habitats around the world, supports the assessment of the conservation status of amphibian biodiversity and informs the general public of amphibian conservation-related issues and priorities. This is attained by supporting and mobilizing a global network of members to develop capacity, improve coordination and integration so as to achieve shared, strategic amphibian conservation goals. For more information about the ASG, visit <www.amphibians.org/asg>.

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The **Critical Ecosystem Partnership Fund** is a joint initiative of l'Agence Française de Développement, Conservation International, the Global Environment Facility, the Government of Japan, the MacArthur Foundation and the World Bank. A fundamental goal is to ensure civil society is engaged in biodiversity conservation. For more information about CEPF, visit <www.cepf.net>.

Conservation International (CI) applies innovations in science, economics, policy and community participation to protect the Earth's richest regions of plant and animal diversity in the biodiversity hotspots, high-biodiversity wilderness areas and key marine ecosystems. With headquarters in Arlington, VA, CI works in more than 40 countries on four continents. For more information about CI, visit <www.conservation.org>.

Pronatura Sur is a non-profit Mexican organization established in 1993, aimed to the conservation of biodiversity and priority ecosystems, promoting sustainable development in harmony with Earth. For more information about Pronatura Sur, visit <www.pronatura-sur.org>.

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Prologue

Throughout this book we describe the characteristics of sites that hold the known range of one or more threatened species—thus the continued existence of these sites is necessary in order to avoid extinction. We compiled information pertaining to these sites including boundaries, habitat quality, threats, land tenure, and potential local conservation partners, as well as data on the populations and distributions of threatened species within them. Such information is extremely useful if one is deciding where among multiple locations to begin conservation efforts and when planning conservation within a given site, yet it is rarely compiled in a systematic way.

Government agencies, NGOs, and multilateral development entities routinely produce conservation plans focused on single sites or regions. However, in our experience, regional plans are vague about where specific interventions ought to occur. Site-level plans tend to be more specific, but there is always a question about why the particular area was selected in the first place and how it fits into a larger framework of conservation. This book is different. It is site-specific while fitting into a widely recognized conservation framework: the Alliance for Zero Extinction (AZE) list of global sites and by extension the *IUCN Red List of Threatened Species*™.

When we were formulating this project we knew southern Mexico was not well summarized in terms of conservation needs. Foundations and international NGOs knew the region held a large number of AZE sites. They had seen their associated lists of species, but these represented little more than dots on a map. With this in mind, we thought many institutions would want to fund a project that compiled basic information about the sites. However, funding for species work was just then becoming difficult to obtain as many organizations began to shift to other priorities. Also, our project was funded at the end of 2007 just as the economic downturn was beginning to make financial support for all conservation more difficult (it is only now starting to return to pre-downturn levels). For this reason, we are very grateful to our funders for supporting what probably seemed like a risky venture.

The risk of financing our project was not simply that it failed to fit the standard funding model at the time. Rather it was that we did not know if we would find any of the highly threatened species or any indication that future conservation work would be able to benefit them. We also were not the ideal candidates for the job. In fact, one of our funders asked us to state why we were the best people to do the work we were proposing, and we answered truthfully that we were remarkably ill-equipped for the task before us. We did not know Spanish, we knew very little about Mexico, and we had no herpetological training. We argued, however, that someone had to try what we were proposing and if no one else was stepping forward, then we would do our best. In retrospect, it is amazing that we were

funded at all. It cannot be easy for donors to defend funding unqualified gringos to research possible Mexican conservation "needs."

We like to think that the gamble paid off. Along with our coauthor, RCH, we found ten (possibly 11) of the 22 highly threatened species we sought and we have produced well-informed overviews of the sites where they occur. In addition, we found a new species of *Plectrohyla* treefrog and several species in the highest IUCN Red List categories that we did not expect to encounter—including one that is often presumed to be extinct.

Throughout the book we show that the potential for numerous amphibian species to go extinct in Oaxaca and Chiapas is high and worthy of being considered a major environmental problem in its own right. We believe the sort of information we have gathered can serve as one of the first steps towards doing conservation at the sites we describe. The measures that could secure amphibians in this part of the world are not without risk, but they are very inexpensive relative to most conservation funding and the potential rewards are great. Indeed, there are few major problems, environmental or otherwise, where one could expect to see large gains made by the investments of a single well-funded organization or even a generous individual—and we believe that is all that it would take. The montane forests of southern Mexico will never be the same if these species are allowed to disappear, and now is the time for someone or some group to take a chance on their survival.

John Lamoreux & Meghan McKnight
Reston, Virginia – 2015

Project Objectives, Scope, and Funding

This report summarizes the findings of a project that began January 2008 and ended July 2009. JFL and MWM jointly conceived the project, sought funding for it, and moved from the United States to Mexico for its duration. RCH started project work in June 2008, and soon became an integral part of the team.

Our project aimed to gather information that could help initiate conservation action at 16 sites in southern Mexico. The sites had been identified in 2005 as being essential to the continued existence of 22 highly threatened amphibian species. During the course of the project, we discovered that the list of priority sites we began with needed to be revised. The recommendations we make in this document about site priorities resulted from the information we gathered. We obtained much of the information from the scientific literature, online specimen databases, and personal communication with experts. We collected the rest directly through fieldwork.

We present site and species information as a series of profiles. We do not intend these profiles to be exhaustive accounts of either sites or species. We sought to discuss some of the inconsistencies or key aspects of the sites and species that have been overlooked in the literature. More importantly, we aimed to provide enough information for the reader to have a basic understanding of the conservation needs of the region's highly threatened species. In many ways we hope that this report will serve as the kind of guide we wish we had had when we started our project.

The project was generously supported by three entities: Conservation International (CI, $8,000), the Critical Ecosystem Partnership Fund (CEPF, $19,989), and the National Geographic Society (NGS, $19,998). Funding from CI and NGS was used for work throughout Chiapas and Oaxaca. CEPF funds were used solely for work pertaining to six species at five sites within Chiapas and portions of Oaxaca east of the Isthmus of Tehuantepec that form the northernmost portion of CEPF's Northern Mesoamerican funding region (Chimalapas Selva Zoque and Sierra Norte de Chiapas; García-Moreno *et al.* 2006[1]). In this report, we do not distinguish between work conducted inside and outside of CEPF's funding region.

[1] García-Moreno, J., Restrepo, J. I., Zavala, S., and S. T. Meyer (eds.). 2006. *Memoria del Taller: Preparación de una Estrategia para la Conservación de Especies Crítica y Globalmente Amenazadas en Mesoamérica Norte. Zamorano, Honduras del 31 de Mayo a 2 de Junio de 2006.* Centro Zamorano de Biodiversidad, Zamorano, Honduras; Conservation International and the Critical Ecosystem Partnership Fund, Arlington, Virginia, USA.

Acknowledgements

We have many people to thank. A project such as this is necessarily collaborative and we were fortunate to have met many wonderful people in the process. Southern Mexico is at a crucial time in terms of conservation and any real progress will depend on the participation of local inhabitants. The communities where we worked were welcoming and genuinely interested in our project. We are grateful for this generosity. We owe a special thanks to those who allowed us to interview them, as well as to those who were eager to accompany us when looking for amphibians.

For helping us look for amphibians within their communities, we thank: Juan Luis Perez Hernandez (Bochojbo Alto), Humberto Tovar Aguilar (Doctor Rodulfo Figueroa), Marcelino (Jolpajalton), Felipe Hernandez Hernandez (La Esperanza), Julian Hernandez López (La Esperanza), Salvador Gonzalez Diaz (Pilalchen), Manuel Lunes López (Pilalchen), Agusto Ruiz López (Pilalchen), Alberto (San Juan Chamula), Marcelino Gomez (San Juan Chamula), Jorge Hernandez Cruz (San Juan Chamula), Martín Jimenez Luis (San Juan Chamula), Mario & Marcel Santis Acoval (San Juan Chamula), Celio Cruz (San Pedro y San Pablo Ayutla), Sara Olivera (San Pedro y San Pablo Ayutla), Ceferino Bautista Alonso (Santa María Huitepec), Luis Antonio Bautista Alonso (Santa María Huitepec), Eleodoro Diaz Gomez (Santa María Huitepec), Alfredo Arnulfo López López (Santiago Comaltepec), Heleodoro Castro (Santiago Comaltepec), Celevin Jimenez Ramirez (Santo Tomás Teipan), Epifanio López Mendoza (Santo Tomás Teipan), Juan Mendoza Ortega (Santo Tomás Teipan), and Mario López Luna (San Martín Soyolapan).

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Our work would not have been possible without the help of Luis Antonio Muñoz Alonso ("Antonio Muñoz" throughout) and Nora Patricia López León. We constantly drew upon Antonio's instructions regarding species identification and savvy when conducting field research in southern Mexico. More importantly, Antonio and Nora were always patient, good-humored, and inspiring. Antonio also introduced RCH to JFL and MWM, and served as one of his thesis advisors. We owe a special thanks to other friends who accompanied us on field trips. Claudia Berenice Serrano Maldonado, Hever Vázquez Gordillo, and Carolina Anahí Zenteno Mancilla helped

us on multiple occasions by making the trips fun and by making some of the best finds! Felix Gonzales Cruz, Luis Márquez, and Roberto Perez Gomez helped us on important excursions as well.

We are indebted to Bela Wood for her generosity and guidance in all things Chiapeneco. It is impossible to enumerate the number of ways Bela rescued us. She was our number one companion throughout our stay. We thank Gary Chandler and Liza Prado, and Linda & Andrew Waterman for long discussions, late nights, and for making our time in Mexico an enjoyable one.

We thank each of our funders for their generous support: the Critical Ecosystem Partnership Fund, the National Geographic Society, and Conservation International. The staffs of these institutions were tremendously accommodating. In particular, we would like to recognize Tim Watkins and Luisa Arnedo (NGS), and Michele Zador (CEPF). Laura Johnston and Tina Schneider (in support of CEPF) were also very helpful.

Conservation International and Pronatura-Sur provided important scientific and logistical support. Jaime García Moreno and Ruth Jiménez of CI (at the time) constantly encouraged us in our work and championed our approach to gathering conservation-relevant data. Mónica Morales (CI) and Israel Amezcua Torrijos (Pronatura-Sur), as well as the rest of the staff of Pronatura-Sur, provided much needed logistical support. The Department of Wildlife and Fisheries Sciences at Texas A&M funded JFL halftime while in Mexico to edit mammal accounts for the *IUCN Red List of Threatened Species*™ as part of their role in the Red List partnership. Although this work was not relevant to our project, the money earned was essential to keep our project going. Thomas Lacher (Texas A&M) was encouraging and wonderfully flexible in allowing us to schedule field trips.

Manuel Grosselet and Georgita Ruiz were extremely helpful to us when we were in our initial grant writing frenzy. They helped write and review proposals on a moment's notice and we are forever grateful for this.

Thanks to Luis Carrillo and AfriCam Safari for coming to San Cristóbal to pick up our frogs for captive breeding at the zoo in Puebla (see "*Plectrohyla acanthodes*," page 201). Luis gave us useful advice for rearing treefrogs and inspires hope for species that are in jeopardy.

We have many people from IUCN to thank. We thank Simon Stuart, Chair of the IUCN Species Survival Commission, for advice on a number of fronts, especially with regard to publishing our book as an IUCN Occasional Paper. We also thank Simon for putting us in touch with Kevin Zippel (Amphibian Ark) and ultimately

with Luis Carrillo. We thank Ariadne Angulo and Phil Bishop, co-chairs of IUCN's Amphibian Specialist Group, for helping us publish with IUCN and for allowing us to use their logo. We wish to thank the former again for useful comments concerning threats to amphibians. We thank Tom Brooks, Head of IUCN's Science and Knowledge Unit, for being the first to read our book cover-to-cover, for the wonderfully detailed comments he provided, and for strong encouragement for our project throughout. Penny Langhammer, co-facilitator of ASG's Working Group on Infectious Diseases and co-chair of IUCN's Task Force on Biodiversity and Protected Areas, was extremely helpful with comments regarding conservation strategies. Deborah Murith and Lynne Labanne (IUCN) helped to format and promote our book, which has made it more attractive and likely to be read. Others from IUCN, especially Neil Cox, Craig Hilton-Taylor, and Mike Hoffmann helped by answering questions, providing data, and giving encouragement. Don Church, Robin Moore, and Jan Schipper (all from CI at the time, but with strong links to IUCN) were helpful in a similar manner. Don and his father, Jon Church, also introduced MWM and JFL to fieldwork in the region during a memorable trip in June 2007.

We thank the many herpetologists who graciously endured our random questions about amphibians in southern Mexico. Roberto Luna Reyes was particularly helpful in allowing us access to INHE specimens. Thomas Bille, Toby Hibbitts, and Eric Smith sent us photos of key species. Jonathan Campbell, William Duellman, James Hanken, Joseph Mendelson, Ted Papenfuss, Gabriela Parra Olea, Sean Rovito, Georgina Santos-Barrera, Eric Smith, Vance Vredenburg, and David Wake provided valuable insights. These experts always promptly replied to our requests, which is remarkable considering the fact that they are the *Who's Who* of herpetology for the region. Their enthusiasm for amphibian research is infectious and their commitment to conservation undeniable. Simply put: efforts to save species in the region would be impossible without their decades of hard work.

We are grateful for our communication with the editors of AZE (2010). We are especially indebted to Juan Martínez-Gómez, who never stops fighting on behalf of Mexico's threatened species. We thank Matt Foster, Mike Parr, Ben Skolnik, Amy Upgren, and the participants of Mexico's national AZE meeting held in Cozumel, June 2010, for their work in making proposed AZE sites for our region official.

Thanks also to Marcy McKnight and Wyatt Crawley for copyediting the book. Every page was improved because of their keen eyes and attention to detail.

Finally, we thank our families who gave us support and encouragement throughout the course of our project.

Text Conventions

- The phrase, "our region," refers to Chiapas and Oaxaca, Mexico.

- For simplicity, we often shorten *IUCN Red List of Threatened Species*™ to "IUCN Red List" or just the "Red List."

- We use standard abbreviations for Red List categories: EX (Extinct); EW (Extinct in the Wild); CR (Critically Endangered); EN (Endangered); VU (Vulnerable); NT (Near Threatened); LC (Least Concern); and DD (Data Deficient) (see Figure Text Conventions-1; Appendix 1). Species that are CR, EN, or VU are considered threatened (IUCN 2012). Occasionally we refer to species being Possibly Extinct (PE) on the Red List. IUCN is cautious about categorizing a species as Extinct. Species that are likely to be extinct (but not confirmed as such) are flagged in the internal Red List database as being PE (Butchart *et al.* 2006; IUCN-SPSC 2014). All PE species are categorized as CR, thus often appearing as CR (PE). Appendix 2 is the full list of CR (PE) species for Mexico. Unless we give specific information to the contrary, all IUCN listings used throughout the document refer to the 2013.2 version of the Red List. These listings as well as the information from Red List species accounts were current as of May 2014 when we downloaded them; the most up to date Red List accounts are available online at: www.iucnredlist.org.

- Because Alliance for Zero Extinction (AZE) criteria are based on the IUCN Red List, we use species names as they appear there. There are three notable exceptions to this practice. First, we might list species from the previous version of AZE to show how the list has changed over time. Second, names might depart from the current Red List when they appear within a referenced quotation. There are a few other instances where synonyms are used in the text for specific purposes, but in each case we also give the current name.

  A third exception includes three species for which expert reviewers of the manuscript (specifically, pers. comm. from S. Rovito and D. Wake) urged us to change based on information that has not yet been incorporated into the Red List. Two salamanders had been thought to be the sole representatives of the genus *Ixalotriton*, but were subsequently moved to the genus *Pseudoeurycea* by Frost *et al.* (2006). The Red List follows the arrangement by Frost *et al.*, but increasingly authors are choosing to follow Vieites *et al.* (2011) and Wake (2012) who resurrected the genus *Ixalotriton* (e.g., Raffaëlli 2013, Rovito *et al.* 2013, Wilson *et al.* 2013, Parra-Olea *et al.*

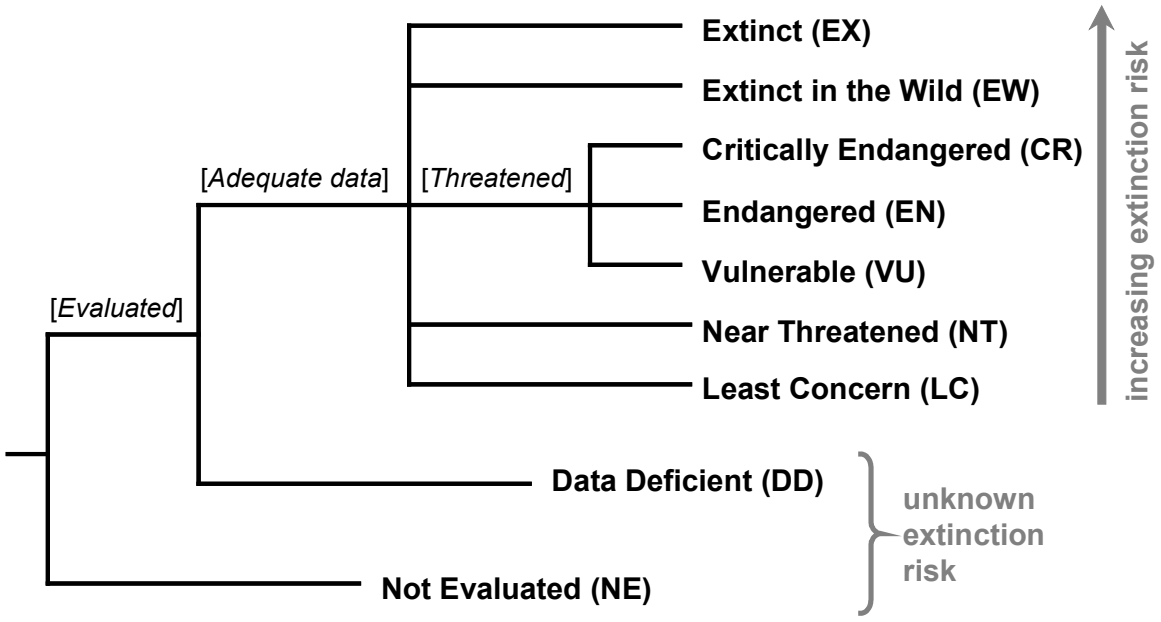

Fig. Text Conventions-1. IUCN Red List categories (from Hoffmann *et al.* 2010).

2014). We, too, have chosen to use *Ixalotriton* for these two species. The third species for which we use a different name than the Red List appears on the latter as *Cryptotriton adelos*. Recent work has shown that this species in fact belongs to the genus *Thorius* (Wake *et al.* 2012), and this will likely be changed in a future version of the Red List.

- Quotations from Red List species accounts are not accompanied by page numbers because the accounts appear without page numbers on the web.

- We do not follow a consistent convention for abbreviating genus names. In a scientific paper, authors usually give the full scientific name for a species when it first appears in the text and at the beginning of a sentence. Elsewhere, that species' genus name is abbreviated to a single letter. Because the length of this report is much greater than most papers, we give the full name of a species more often than would otherwise be the case.

- Common names of species are capitalized throughout this report.

- Site names are placed in quotes when referring to previous versions of the AZE list.

- The term "trigger species," or just "trigger" as a noun, refers to a species that qualifies a site for AZE designation. All trigger species are by definition either EN or CR on the Red List.

- The Alliance for Zero Extinction has released two official datasets (both from <www.zeroextinction.org>). The first of these was released in 2005 and throughout the text we refer to it as the "original AZE dataset," AZE (2005), and sometimes as Ricketts *et al.* (2005), which was a paper that was written using these data. With the exception of Ricketts *et al.* (2005), we do not include a citation for the 2005 AZE dataset in the various reference sections. AZE (2010) is the current official list (both of species and sites) and it is properly referenced wherever it appears.

- We refer to the extent of occurrence (EOO) and range of a species interchangeably. EOO is an important concept because it has direct bearing on the criteria for listing a species on the Red List. There is a technical difference between an EOO and a species' range size as derived from GIS polygons. In practice, this distinction rarely, if ever, matters when there is just a single, small polygon, which is the case for AZE trigger species. For a definition and explanation of EOO, see IUCN (2012).

- We make a distinction between collecting localities, and locations or sites. When we speak of locations or sites we are talking about places that could qualify for AZE listing (see page 4). These are units that are relevant to the conservation of a species and are usually the same as "locations" within the Red List criteria (see Appendix 3). Collecting localities are the places where a species has been recorded. Sometimes a small, contiguous forest along a road will have more than one locality. To us, the entire forest would be a single location. It sounds like a subtle difference, but it is substantial; a prominent museum collector once told us that to a herpetologist a locality is basically wherever the car stops.

- We begin each of the Part II site accounts by listing the amphibian trigger species for that site. We also include "Last Year Observed" (LYO). This date is the most recent year from which the trigger species is known to researchers. We explain our sources for each of the dates within the site account text—being from the published literature, Red List accounts, personal communication, or from museum specimen records. For some species we list "recent" as the LYO, because we have indications that the species has been found at least within the last few years, but we do not have an exact date.

- The site profiles contain phrases like "two years ago a large storm washed the road out." In situations like this, the stated time is in relation to our last visit to the site, which is listed at the beginning of the site profile. Thus,

"two years" in the past is not 2013 (two prior to the writing of this report), but rather from when we were actually at the site.

- Museums are crucial for conservation. The specimens that these institutions curate serve as the basis for our understanding of the relationships between organisms. For the vast majority of species, specimen records also provide the most reliable information about their distribution, especially over time. Thus, access to museum records is important for conservation practitioners. In the past, those without direct access to a museum had to rely on correspondence with museum staff for information about specimen records or on documentation published by someone with access. Thankfully, most large museum collections and an increasing number of smaller ones now put their data online, which has greatly enhanced the conservation impact of these institutions.[2]

  We used several online databases that retrieve specimen records, including: HerpNET, Vertnet, GBIF, KUH's specimen collection (via Specify 5 Web Access), MVZ's Arctos, and CONABIO's REMIB. Of these, we relied most heavily on HerpNET, which is a network of herpetological collections. At the time of writing, more than 5.5 million specimen records belonging to 64 institutions worldwide could be searched through its portal <www.herpnet.org>. Within our report, we note the year in which we accessed databases for species specimen records, but we do not list these citations in the reference sections. All HerpNET (2014) records were retrieved by us on 26 May 2014. UNAM HerpNET records for a number of species that appeared in 2009 were unavailable on 28 December 2011. At the time, O. Flores-Villela informed us that UNAM's HerpNET server had been down for several months. We have double-checked each of the UNAM records on REMIB and HerpNET (both in May 2014), but in most cases locality data, name of collector, and date of collection are still unavailable to the public. Where we have more information from HerpNET in 2009, we report it.

  Every museum scientist will tell you that you cannot blindly accept all specimen records as fact. As with any large dataset, errors will inevitably creep in no matter how vigilant the curator. More specifically, records listed in a database for a species might actually refer to a different species.

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[2] Similar to the revolution in access to museum records is the access to early publications that is made possible by the *Biodiversity Heritage Library* and its contributing institutions. We do not have a text convention to note in this regard, but the resource is something that the reader ought to know about. If we needed an early species description or a classic paper, we could usually find it at: <http://www.biodiversitylibrary.org/>. It is truly an amazing resource.

This can happen if the specimens were misidentified or taxonomic changes have occurred that the listing institution has not incorporated. At times, the failure to incorporate newer information is by choice (i.e., taxonomists disagree) or because there are too many changes for the museum to keep up with. Specimen locality information also varies greatly in terms of precision and accuracy. We are not taxonomists; therefore we were unable to put a professional's critical eye to the records of our species. We have done the best we could to point to inconsistencies and possible anomalies throughout the text. Our maps and discussions of species' ranges are neither generated nor informed by online mapping tools. Typically the latitude and longitude data informing such tools are estimated post-collection and often approximated to the nearest town. This might be fine for certain purposes, but in this report we needed to take a more detailed look species-by-species and often locality-by-locality. For instance, if one of our species was said to be collected five kilometers west of Santa María, that five kilometers was important to us.

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I: INTRODUCTION

Layout of the Book

In Part I, we briefly introduce the Alliance for Zero Extinction (AZE), which served as the framework for our selection of sites in which to work. We discuss its membership and the way its list of species and sites is derived from the IUCN Red List. We also mention how the international community is beginning to value AZE. Understanding AZE will help guide the reader through the rest of the book. We then summarize the plight of Mexican amphibians and the challenges facing anyone who wishes to conserve them. The bulk of the introduction, however, discusses five threats to amphibians living in the montane forests of Chiapas and Oaxaca. The threats will reappear at times within the site profiles that subsequently follow, but here we describe some of the background information and context for the threats in relation to the region as a whole.

Parts II and III are a series of site profiles, which make up the heart of the book. The profiles discuss the sites and the species they contain in a user-friendly manner. Our field work is woven into each profile both in terms of reporting on species we found and locals with whom we spoke. If the reader is familiar with the conservation concerns of southern Mexico, or has limited time and can only read a portion of our book, Parts II and III are where they should start (i.e., skip to page 89). We hope that others see value in the way we have approached sites in these sections, and perhaps someone will try it elsewhere in Chiapas and Oaxaca, or even farther afield.

Parts IV and V are supplementary materials of a technical nature. Part IV is a series of recommendations we submitted to AZE to improve the 2005 list. The vast majority of these were adopted by the current (2010) AZE list. Part IV will be of interest to those who want to understand the issues behind the delineation of AZE sites. It also lays out a wider program of conservation priorities for southern Mexico than we were able to address through site visits. Part V begins with our observations about conserving amphibians in places where disease is a major threat. We get a sense that there is more pessimism or hopelessness on the part of amphibian conservationists and funders in terms of what can be done in areas affected by disease than is warranted. Because the case we make is both highly opinionated and not directly tied to the theme of sites and species upon which the rest of the book is based, we leave it as an add-on. The remainder of Part V consists of appendices that will help readers who wish for more information about the Red List and maps of AZE sites in relation to protected areas. We refer the reader to specific appendices at different points within the main text.

Alliance for Zero Extinction (AZE)

This report focuses on sites and species within Chiapas and Oaxaca that qualify for Alliance for Zero Extinction (AZE) designation. AZE is a consortium of 93 non-governmental organizations (NGOs)[1] that work to protect species that are likely to go extinct without immediate conservation action. The alliance criteria for choosing sites and species are straightforward:

1. **Endangerment.** An AZE site must contain at least one Endangered (EN) or Critically Endangered (CR) species, as listed on the IUCN Red List.[2]

2. **Irreplaceability.** An AZE site should only be designated if it is the sole area where an EN or CR species occurs, contains the overwhelmingly significant known resident population of the EN or CR species, or contains the overwhelmingly significant known population for one life history segment (e.g., breeding or wintering) of the EN or CR species.

3. **Discreteness.** The area must have a definable boundary within which the character of habitats, biological communities, and/or management issues have more in common with each other than they do with those in adjacent areas.[3]

What makes AZE successful is its simplicity. The member NGOs vary in their approaches to conservation, but all agree that if a highly threatened species exists in only one site, then the protection of that site is essential to the survival of the species. Each partner organization agrees to the list of sites and the identification process, and virtually all have a special interest in conserving a particular subset of sites and species. Since its inception in 2000, alliance members have protected numerous species that otherwise would have gone extinct.

Increasingly, AZE sites are being recognized as essential targets for conservation and as indicators of a country's commitment to biodiversity (see Butchart *et al.* 2012). AZE has been welcomed by the G8+5 environment ministers through the Potsdam Initiative (2007), and was included as an indicator for the Convention on Biological Diversity's 2010 target by the Biodiversity Indicators Partnership (BIP 2010). The ecosystem services that the sites provide are also incredibly important (Larsen *et*

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[1] As of May 2014: <http://www.zeroextinction.org/parnters.html>.

[2] CR and EN are the two highest threat categories on the Red List. See Figure 1 of Text Conventions (page xx) and Appendices 1 and 3 for information about the *IUCN Red List of Threatened Species*. For an expanded explanation of the Red List we refer the reader to Mace *et al.* (2008). Also worth reading are the categories and criteria (IUCN 2012), which explain how species are placed on the Red List. For summaries of Red List findings see Vié *et al.* (2009) and Hoffmann *et al.* (2010). In addition, there are several papers that discuss what makes the Red List unique and especially useful for conservation (e.g., Lamoreux *et al.* 2003; de Grammont & Cuarón 2006; Rodrigues *et al.* 2006; Hoffmann *et al.* 2008).

[3] We take this description of the AZE criteria verbatim from AZE (2005).

al. 2012). AZE sites are used by the Environmental Performance Index to measure progress toward protecting critical habitat (Hsu *et al.* 2014). In addition, the governments of Colombia and Brazil have adopted AZE into their biodiversity planning, and it serves as the basis for the most comprehensive site-level prioritization for Mexican biodiversity to date (i.e., Ceballos *et al.* 2009). Each of these countries, as well as India, has formed a national AZE consortium (see Table I-1 for a list of Mexico's partner organizations).

1. Fundación Plan Estratégico de Cozumel
2. Sociedad para el Estudio y Conservación de las Aves – CIPAMEX
3. Endémicos Insulares
4. Bosque Antiguo
5. Mater Natura
6. Canasta de Semillas
7. Naturalia
8. Asociación Mexicana de Zoos y Acuaria
9. Fundación de Parques y Museos de Cozumel
10. Conservación de Islas
11. Pronatura
12. Sin Fronteras
13. Parque Ecológico Macuiltepetl - Museo de las Aves de Veracruz
14. Sacbé
15. IBUNAM
16. The Nature Conservancy México
17. Reserva Ecológica el Edén
18. Ayuntamiento de Cozumel
19. Amigos de Sian ka´an

Table I-1. National Alliance for Zero Extinction members for Mexico. The list comes from <http://www.zeroextinction.org/parnters.html> and was viewed April 2014 (also as of April the lead for Mexican AZE sites is Patricia Escalante of UNAM).

We began our project investigating sites and species according to the 2005 global AZE list (Ricketts *et al.* 2005), but a new list was released in November 2010 (AZE 2010). In Part IV, we discuss a number of reasons why the Mexican sites and species on the 2005 AZE list needed to be updated. One of us, JFL, was responsible for drafting most of the Mexican portion of the new list (i.e., all non-bird species) with input from our project. Part IV will be of interest to anyone concerned with AZE sites in southern Mexico. Only here are we able to expand on why something made or did not make it onto the list.

Mexico's Extraordinary Number of Amphibian AZE Sites

Amphibians make up the largest portion of the global AZE list with just over half of the species (508 out of 920, or 55.2%) (AZE 2010). Mexico has 377 amphibian species (Parra-Olea *et al.* 2014; González-Hernández *et al.* 2014)—the fifth most of any country—and it ranks second (to Colombia) in number of threatened amphibians with 211 (Hilton-Taylor *et al.* 2009). However, Mexico has by far the greatest number of AZE sites (68) and species (151) (Figure I-1). Most of Mexico's AZE species are amphibians (98 or 64.9%), and they trigger the majority of sites (39 or 57.4%). About one-third of Mexico's amphibian AZE sites and species are found in Chiapas and Oaxaca—despite the fact that this represents only a small portion of

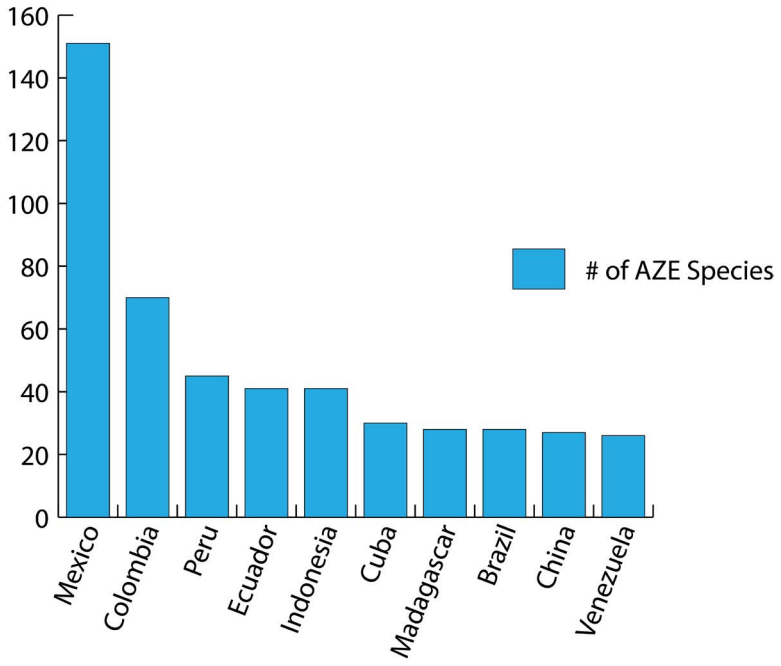

Fig. I-1. Top 10 countries in number of AZE trigger species. Mexico has more AZE sites and species than any other country (with more than double the trigger species of Colombia, the country with second highest total, and more than any continent outside the Americas).

the country's land area (28.2% sites; 33.7% species) (Appendix 4).

Chiapas and Oaxaca are recognized as globally important areas in terms of conservation for a wide range of taxa (Brooks *et al.* 2006). Vertebrate species richness and endemism here are high relative to the rest of the world (Lamoreux *et al.* 2006), as are rates of species turnover between sites (Wake 1987; Wake *et al.* 1992; McKnight *et al.* 2007). The diversity of amphibians in this topographically complex region is particularly outstanding (Flores-Villela 1993; Ochoa Ochoa & Flores-Villela 2006; Ochoa-Ochoa *et al.* 2014). Indeed, Chiapas and Oaxaca are the top two states in terms of number of amphibian species (Parra-Olea *et al.* 2014), and new species of frogs and salamanders continue to be described (for a discussion of recent descriptions see footnote 3 page 225).[4]

[4] New species of amphibians continue to be described at an amazing rate all over the world (Hanken 1999; Collins & Halliday 2005; Köhler *et al.* 2008; Rodrigues *et al.* 2010). In Mexico, most new amphibian species descriptions are accompanied by a disclaimer about there being additional species that need to be described. For example, when Parra-Olea *et al.* (2010:64–66) named *Pseudoeurycea cafetalera* from Veracruz they stated, "the taxonomy of *Pseudoeurycea* is still not fully resolved, with 6 species recently described (in addition to *P. cafetalera*) and several more species awaiting description." Similarly, Wake and Vredenburg (2008) mention 3–5 additional *Thorius* salamanders that await description from our region and they suspect that this is not unusual here. During our project, we found a new treefrog of the genus *Plectrohyla* from Chiapas. This frog is morphologically distinct both as an adult and as a tadpole (see page 206). It is interesting to note that new salamanders in Mexico tend to be described along with genetic data (though not always; e.g., Parra-Olea

State of Urgency

The conservation outlook for amphibians worldwide is bleak. Blaustein and Wake (1990:203) pointed to the seriousness of amphibian declines, which appear "to have begun, for many species, in the early to mid 1970s." The problem has only gotten worse.[5] This is troubling to anyone who cares about species in general, and it also has devastating consequences for ecosystems.[6]

Amphibian declines and disappearances are so severe that Wake and Vredenburg (2008) assessed whether the entire class is in danger of being eliminated. Although the authors concluded that all amphibians will not disappear in the short term, it is hardly a sign of encouragement. Similarly, Lips and Mendelson (2008:105) wrote that "we are facing the synchronous extinction of a significant proportion of an entire group of vertebrates, and we propose that it is no longer correct to speak of global amphibian declines but, more appropriately, of global amphibian extinctions." Globally, 41% of amphibian species are estimated to be threatened with extinction, which is the highest proportion of any class of vertebrates (Hoffmann *et al.* 2010).[7] In Mexico, 57.8% of amphibian species are listed as threatened on the

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et al. 2005a), but frogs rarely (if ever) are. We know of a few exceptions where Mexican populations of a North American frog species have been split from US populations based on genetic data, but not a wholly new find. For example, *Gastrophryne mazatlanensis* Taylor (1943) was resurrected as distinct from *G. olivacea*, which ranges widely in the US, by Streicher *et al.* (2012). Presumably there are cryptic frog species entirely within Mexico that should be split in a similar manner to salamanders (and like the numerous examples from frogs in other parts of the world; e.g., Stuart *et al.* 2006; Fouquet *et al.* 2007; Vieites *et al.* 2009; Funk *et al.* 2012; Biju *et al.* 2014).

[5] Following the observation by Blaustein and Wake (1990), a number of others began to write about amphibian declines as a global phenomenon and over time researchers have learned more about the extent and causes of the crises (see Wyman 1990; Wake 1991; Blaustein *et al.* 1994; Blaustein & Wake 1995; Wake 1998; Duellman 1999; Houlahan *et al.* 2000; Stuart *et al.* 2004; McCallum 2007; Sodhi *et al.* 2008; Wake & Vredenburg 2008; Collins 2010; Wake 2012).

[6] For reviews of the ecosystem services amphibians provide see Valencia-Aguilar *et al.* (2013) and Hocking and Babbitt (2014). For the nutrient benefits from Neotropical frogs in particular see Whiles *et al.* (2006, 2013) and Connelly *et al.* (2008, 2014); for temperate salamanders see Davic and Welsh (2004) and for the argument that similar ecosystem functioning from salamanders are likely to extend to the tropics see Rovito *et al.* (2009a); and for a surprising finding that salamanders can reduce the populations of organisms that decompose woody debris, thus producing a measurable degree of carbon storage see Best and Welsh (2014). However, amphibians are important for more reasons than ecosystem function or the ecosystem services they provide (for reviews see Cox *et al.* 2008 and Halliday 2008).

[7] This estimation includes a proportion of DD species as threatened that is equivalent to the proportion of threatened amphibians that had been assigned a non-DD category. In other words, 30% of amphibians are considered threatened (higher than any other terrestrial vertebrate group), but 26% are listed as DD (again, the highest percentage of any terrestrial vertebrate group). When Hoffmann *et al.* (2010) asked how many of the 26% were likely to be threatened, they applied the same 30% percent to the DD species to reach the estimate of 41% for amphibians overall. According to Wilson *et al.* (2013), this is an

Red List and an additional 38 species (10.4%) are DD.

Threats to Amphibians in Chiapas and Oaxaca

Amphibians face a number of threats in Chiapas and Oaxaca. In the site accounts, we discuss specific threats to AZE species within a local context. In the current section, we discuss five major threats: habitat loss, water use, fire, climate change, and chytridiomycosis. The latter is a fungal disease that affects a number of amphibian species, which has recently become a major threat. Our objective is to provide some background about these issues to help inform the site accounts that follow.

Our list of threats is somewhat unusual. We do not include three standard threats: non-pathogenic invasive species, over-exploitation, and contaminants. Collins and Storfer (2003) included these as topics in their review of the factors behind global amphibian declines, and each is considered a threat to species in Mexico (Frías-Alvarez *et al.* 2010). Invasive species, however, are not an over-arching concern in our region. There are invasive species here, but because they are potentially a major threat for only one of our amphibians (*Pseudoeurycea aquatica* CR (PE)) we discuss that possibility within the relevant site account (see page 156). Similarly, over-exploitation is not a major threat here like it is in Southeast Asia (Warkentin *et al.* 2009), although it is a serious problem for a few amphibians elsewhere in Mexico—most notably the Axolotl (*Ambystoma mexicanum* CR), an aquatic salamander on the southern edge of Mexico City (Griffiths *et al.* 2008; Zambrano *et al.* 2010). It is hard to determine whether or not chemical contaminants are a problem for amphibians inhabiting the montane forests of Chiapas and Oaxaca. We have no reason to believe they represent a major threat, and we suspect they are of minor concern—but the evidence is so scant that it is impossible to evaluate at present (see Box I-1, page 10).

Our list of major threats is also unusual for what it includes. Water use and fire are not typically regarded as threats to the existence of amphibian species. These two topics, however, are of special concern in southern Mexico. Logically, both water use and fire would be considered forms of habitat loss, and our separation of them into different groups was made mainly out of convenience because each has aspects that make them easier to discuss as stand-alone issues.

The first four major threats—habitat loss, water use, fire, and climate change—are often intertwined in the sense that none of them occurs in isolation. Deforestation as a form of habitat loss, for instance, degrades water quality and can lead to

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underestimate.

changes in climate.[8] Climate change in turn has increased the devastation of fires. In these examples, threats interact by increasing the prevalence or the intensity at which they are witnessed on the landscape. Chytridiomycosis might also interact with other major threats, but the degree to which these interactions impact (or perhaps reduce impacts on) amphibians is far from resolved.

Considerable debate exists over whether chytridiomycosis prevalence or severity is connected to other major threats. There are likely to be indirect interactions between chytridiomycosis, the other threats, and a species' risk of extinction. For example, deforestation could reduce the distribution of a species making it more susceptible to extinction from the disease. Direct interactions between chytridiomycosis and the other threats, however, are not universally accepted. The interaction, or lack thereof, between climate change and chytridiomycosis is the most contentious issue among researchers. We discuss this debate later in this section (see Box I-2, page 54). Furthermore, there is evidence that deforestation and fire can create habitats that are beneficial to disease-susceptible amphibians. We discuss these findings towards the end of this chapter when listing possible reasons why some individuals or populations of susceptible species persist when confronted by the disease while others do not (see page 49).

Habitat loss

Most threats to amphibians constitute some form of habitat loss. Deforestation is the most obvious threat to amphibians. All of the AZE amphibians we studied live in montane forest. Some of these species can be found within roadside banks or along rivers, but even these species are ultimately tied to forests. In Mexico, there are AZE species, such as the Tropical Pocket Gopher (*Geomys tropicalis* CR) in Tamaulipas, that are found in lowland habitats with few trees, but none of these species happened to be under our purview. This means that when deforestation occurs at our sites it has serious consequences.

Deforestation continues to greatly outpace reforestation both globally (Hansen *et*

[8] Deforestation changes the climate at multiple spatial scales. At a small scale, the edge effects of deforestation can alter microclimates along a forest border, drying amphibian habitats (Urbina-Cardona *et al.* 2006; Santo-Barrera & Urbina-Cardona 2011). When we speak of climate change, we typically mean regional or global changes. Here, too, deforestation has a major impact. At a regional scale, lowland deforestation can affect rainfall patterns (Pielke *et al.* 2007) and lift the base heights of clouds, which creates drier conditions in montane forests (Lawton *et al.* 2001; Ray *et al.* 2006). Globally, deforestation releases enough greenhouse gases to rival the entire transportation sector (including buses, cars, trucks, trains, ships, and aircraft) (Rogner *et al.* 2007; for updated, yet similar, estimates of deforestation emissions see van der Werf *et al.* 2009). Deforestation emissions are overwhelmingly dominated by the tropics (Le Quéré *et al.* 2009). In fact, land use (including both deforestation & agriculture) is collectively the number one source of greenhouse gas emissions in most tropical countries (DeFries & Rosenzweig 2010).

Box I-1. The Possible Threat of Chemical Contaminants

There is a large literature on the adverse effects of chemicals on amphibians in laboratory and field settings. In some localities high levels of dangerous substances directly reduce populations, and chemicals in combination with other threats can decrease individual survival (Rohr *et al.* 2004; Boone *et al.* 2007). Sublethal negative effects of contaminants on the behavior and physiology of organisms have also been documented (Weis *et al.* 2001). There is no evidence that chemical contaminants are a threat to the species within our sites at this time, but this says more about the lack of data than about the degree of threat.

Our montane sites are usually not close to large industrial, agricultural, or metropolitan areas. There is, however, increasing concern about the levels of some organochlorine pesticides in the mountains of southern Mexico (Alegria *et al.* 2008). The worry is that chemicals used for agriculture and for public health measures aimed at reducing disease vectors (i.e., mosquitoes) in populated areas are transported through the air and deposited at higher elevations. We are unaware of a published link between pesticides and amphibian declines here, but such concerns have been raised elsewhere. For instance, pesticides from the lowlands of central California appear in the Sierra Nevada mountains (McConnell *et al.* 1998; LeNoir *et al.* 1999), those from the lowlands of Belize are found in nearby mountains (Kaiser 2011), and they are present in montane forests throughout Costa Rica (Daly *et al.* 2007a,b). In each of these areas there has been speculation about the effects on amphibians (California: Davidson *et al.* 2002, Davidson 2004; Belize: Stafford *et al.* 2010; Costa Rica: Daly *et al.* 2007b). Yet in the example of the Sierra Nevada mountains, it appears that pesticides have played no role in amphibian declines (Bradford *et al.* 2011); these declines are overwhelmingly due to predation by introduced trout (Knapp & Matthews 2000; Vredenburg 2004) and to chytridiomycosis (Briggs *et al.* 2005; Rachowicz *et al.* 2006; Vredenburg *et al.* 2010).

Perhaps the chemical of greatest concern to people in the region is dichlorodiphenyltrichloroethane (DDT). There are likely other chemicals used in agriculture that have a greater potential to negatively affect amphibians, but data for these are not available. That said, information about DDT might be informative in terms of assessing risk from chemicals used in the agriculture sector more generally. Surveillance for pesticides in our region has been confined to two locations near the Guatemalan border (in the city of Tapachula and adjacent mountains) (Alegria *et al.* 2006, 2008; Wong *et al.* 2008, 2009, 2010). No surveillance has been conducted near the sites we visited, despite the fact that Oaxaca has been singled out as a high priority for air quality sampling (Wong *et al.* 2009, 2010). From 1947–2000, Mexico used more DDT than any other Latin American country (Li & Macdonald 2005), and Oaxaca and Chiapas had the highest rates of use for public health in the nation (there are no data for crop use by state) (Wong *et al.* 2009). In 1997, Mexico set a goal of reducing DDT use by 80% by 2002 under the North American Regional Action Plan (CEC 1997), but the country reported an early end to usage in 2000 (CEC 2003). Still, DDT has been detected

by passive air samplers in the mountain site near Tapachula at very high levels.[1] Some of the DDT detected is old material revolatilized from soils; however, much of the DDT is "fresh." The degree to which it represents illegal usage in Mexico versus use in countries to the south is unknown (Wong *et al.* 2009). It is likely that levels of DDT and other chemicals are high for some of our sites, but there are no data to support this hypothesis. Even if true, there are as yet no data showing that it adversely affects amphibian populations.

[1] Alegria *et al.* (2008) detected ∑DDT 2360 ± 593 pg m^{-3} in passive air samples at the site. Although this is comparable to other sites in Belize and in Chetumal, Mexico (Alegria *et al.* 2006; Shen *et al.* 2005), it remains higher than any site reported by the global atmospheric passive sampling (GAPS) campaign covering urban, agricultural, and background sites (Pozo *et al.* 2009).

al. 2013) and within Mexico (García-Barrios *et al.* 2009). The montane forests of Chiapas and Oaxaca are no exception to this trend (and some local citizens are concerned about the issue, see Figure I-2). Although deforestation is a familiar threat, its root causes and the many intricacies of its effects can be complex. The loss of forest, for example, does not occur uniformly. As a result, the remaining patches of forest typically become separated from each other by agricultural plots. Growth of human-dominated lands at the expense of forest in this manner is called fragmentation, which has become its own discipline of study. The long-term viability of a fragment depends on its size, configuration (the ratio of perimeter to total area), and distance to other fragments (with which it might be capable of exchanging biota). But, of course, the continued existence of a single fragment is most readily determined by whether or not people decide to cut it down.

In southern Mexico, much of the deforestation is driven by small-scale logging operations, expansion of small-holder farms, or traditional shifting agricultural practices that are incompatible with a rapidly increasing human population. Within the site accounts we mention such drivers, but we are not social scientists. Where we simply say expansion of small-holder farms is driving forest loss at a site, a social scientist would try to find out why this is occurring.

Well-managed protected areas can reduce or eliminate deforestation. There are several forms and levels of protection. In addition to categorizing the degree of threat to species, IUCN (through its World Commission on Protected Areas) records the type of protection afforded to protected areas worldwide—from category I, meaning strict nature reserve or wilderness area, to multiple use zones that include resource extraction (category VI) (Dudley 2008). For comparative purposes, gap analyses that identify species that are wholly outside protected areas first need to

Fig. I-2. Local communities, as well as federal agencies, are increasingly concerned about the loss of montane forests, especially in relation to maintaining reliable sources of water. Sign in the Chimalapas AZE site saying "the forest is life" (top left). Sign saying that the "trees are your lungs, conserve!" near the Cerro de las Flores AZE site (top right). Sign from the community of Santa María Huitepec (bottom left). Federal sign from near Concepción Pápalo (bottom right).

determine what can be considered protection for a species. Typically, these analyses use a subset of stricter protected areas, those within IUCN categories I-IV, as the protected set (e.g., Rodrigues *et al.* 2004). This standard is also useful when comparing the overall percentage of landscapes that are within protected areas.

According to Jenkins and Joppa (2009), 5.8% of the world's land surface is protected within IUCN categories I-IV. 3.4% of Mexico's land area is similarly protected.[9] Chiapas does relatively well with 11.2% protected, while Oaxaca has

[9] We used the public version of April *2014 World Database on Protected Areas (WDPA)* for protected areas in Mexico (IUCN & UNEP 2014). This dataset is updated monthly and is freely available at: http://www.protectedplanet.net/. Within Mexico, we selected terrestrial protected areas marked as IUCN categories I-IV. These category designations are the only way to make comparisons with data in other countries. However, the listings that Mexico submits to the WDPA do not always correspond with what one would expect from Mexico's own management designations. Biosphere reserves are often troublesome in being listed

just 3.2% protected.[10] However, the percent of a given area that is protected is but a small part of the story. Only two of the 34 amphibian trigger species in Oaxaca or Chiapas overlap with a national protected area (Appendix 5).[11] Protected areas in this region are less often situated in the highlands, which is where most of the narrow-ranging amphibians live. The protected areas in Chiapas are dominated by lowland tropical rainforest. Oaxaca's protected areas include the insufficiently-sized Parque Nacional Benito Juárez (which is not listed within IUCN categories I-IV), Yagul archaeological site, a few coastal refuges, and a single large valley biosphere reserve that is shared with Puebla.[12]

Part of the reason the protected area coverage is poor in our region is that communities tend to have a deep distrust of the federal government. The creation of a national park is difficult and unlikely to be the best strategy for conservation in most cases. Therefore, we do not recommend federal protected areas lightly, and in fact we argue for a national park in only one instance (i.e., Cerro de las Flores, see page 213). Conservation in southern Mexico requires community participation

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either without an IUCN category or as category VI, yet they tend to be more effective at preventing land use and land cover change than other types of protected areas (Figueroa & Sánchez-Cordero 2008). For this reason, we added biosphere reserves to the area coverage of protected areas that we report for both Mexico as a whole and for our region. There are, however, exceptions (i.e., biosphere reserves that are poorly protected; see Figueroa *et al.* 2009). To obtain percentage of coverage, we dissolved the protected area layer to eliminate double counting of coverage where management units overlapped. We did not project this final layer so our numbers are not precise, but the percentages we report should be very close, if not identical, to the actual.

[10] We do not include current state protected areas or proposed protected areas in these percentages unless they were specifically given an IUCN category in the WDPA (IUCN & UNEP 2014). Certainly both could be beneficial to species and we know of a few that are (e.g., the state protected area Parque Educativo Laguna Belgica in Chiapas). However, there are few state protected areas in our region (particularly in Oaxaca), and if actions in other states are indicative, these cannot be trusted to be secure. For example, Parque Ecologico Estatal Omiltemi was arguably the most important protected area for biodiversity in Guerrero before becoming degazetted (Flores-Villela *et al.* 2010). It is also premature to count proposed protected areas as being secure. For more on this point, see Johnson *et al.* (2010) who discussed the failure of proposed protected areas in Mexico from the 1990s (as listed in Flores-Villela & Gerez 1994) to materialize.

[11] *Pseudoeurycea unguidentis* is in the Parque Nacional Benito Juárez (*Thorius pulmonaris* is also known from very close by, but has not been located in the park; Parra-Olea *et al.* 2008a,b) and *Craugastor montanus* (EN) in Reserva de la Biósfera El Triunfo (Santos-Barrera & Flores-Villela 2004). *Plectrohyla ephemera* almost certainly exists within the Zona de Preservación Ecológica Cerro de las Flores, but this protected area is classified as a certified "Community Conserved Area" and does not have an IUCN protected area category assigned to it in the WDPA (IUCN & UNEP 2014).

[12] The Tehuacán-Cuicatlán Biosphere Reserve is impressive. See Canseco Márquez and Gutiérrez Mayén (2010) for a detailed account of the herpetofauna (including higher elevation sites outside the reserve). These authors noted that three undescribed amphibian species occur in or near the protected area on the Oaxacan side (2 *Thorius* salamanders and a *Charadrahyla* frog).

to be effective. Within our sites there are a few examples of communities that have taken control of their natural resources and either stopped net forest loss or have reversed the trend (e.g., Sierra de Juárez page 105). We are encouraged by such efforts, but the scale of habitat loss in southern Mexico is too great for many communities to address by themselves.

Despite the distrust of the federal government, there is a role for it. Perhaps partnerships between the federal government and locals can succeed. CONANP (Comisión Nacional de Áreas Naturales Protegidas) started a program of community conservation areas that are certified and supported by the government (for more on this initiative see footnote 1 on page 182). Oaxaca and Chiapas actually do much better in terms of protected area coverage when one includes these lands (Ochoa-Ochoa *et al.* 2009).[13] Some of the community conservation areas overlap the AZE sites in our region and their management will likely determine whether their species survive. WDPA does not list IUCN protected area categories for most of these management areas and it will be important to know how well they are working.

Water use

Water management is a major concern throughout Mexico and at most of our sites. Pre-European Mexico had a long history of irrigation and managed water, and water has always been of great importance. It is not a coincidence that the rain god, Tlaloc, adorns Teotihuácan, while the Mayan rain god, Chac, appears prominently at Palenque and Chichenitza (Nash 2007). Mexico continues to intensely manage water, mainly for agriculture, power generation, and to supply drinking water to its cities. The problem of water management in Mexico is most apparent in the north and central parts of the country. Indeed, these regions have 31% of the natural water availability, yet they contain 77% of the population (CONAGUA 2011). Much of this water is used for agriculture. The country's irrigated land accounts for half of its agricultural production and two-thirds of the exported agricultural output (Ojeda-Bustamante *et al.* 2007). Mexico uses more groundwater than any country in Latin America (Scott & Banister 2008), and it has the sixth largest surface area under agricultural irrigation worldwide (CONAGUA 2011). Two-thirds of the 188 most important aquifers are classified as over-used and another 28% rate as fully exploited (CONAGUA 2003 in Muñoz-Piña *et al.* 2008). Many of the issues in terms of water governance, however, occur within our region as well. Chiapas in particular

[13] Ochoa-Ochoa *et al.* (2009) is a valuable paper that discusses the importance and potential of community managed forests and their certification. The work draws on an amazing compilation of spatial datasets of protected areas, community areas, and socio-economic indicators that the authors compiled, have since updated, and made freely available (see Bezaury-Creel *et al.* 2012). The authors have also shown how these various data layers can be used in a framework to decide how threatened a micro-endemic is likely to be and how to prioritize conservation actions relative to other possible actions, such as field research to confirm the continued existence of species (Ochoa-Ochoa *et al.* 2011).

has been highlighted as a state where water scarcity and adequate sanitation are projected to be especially intense with climate change and a growing population (CONAGUA 2011).

Fig. I-3. Polluted river in San Cristóbal de las Casas.

Mexico's streams and rivers are diverted, dammed, and/or polluted with chemicals, as well as with human and agricultural waste. In 2010, Mexico reached 89.9% coverage in terms of wastewater collected by sewer systems (CONAGUA 2011). However, this measure of "sanitation" appears to be defined by "persons connected to a sewer or septic tank system and those discharging directly to a river, lake, or ravine" (Sanders *et al.* 2013:1305); thus, only 43.4% of wastewater receives treatment (CONAGUA 2011). Problems of sanitation, pollution, over-use, and barriers to aquatic connectivity exist throughout the world (Malmqvist & Rundle 2002; Revenga *et al.* 2005; Döll *et al.* 2009; Vörösmarty *et al.* 2010), but are particularly noticeable in Mexico. Here, roads are constructed and the excess fill is loosely dumped into mountain streams, surface waters in populated areas become open sewers, and riparian buffers are often ignored (Figure I-3). Each of these practices can cause serious problems for amphibians.

Water use starts with water availability. Although the average total annual rainfall across the region has not changed significantly over four decades, patterns of rainfall have (Aguilar *et al.* 2005). The trusted timing of the rainy season and the dry season is less predictable. Precipitation intensity is increasing, as well as the contribution of "very wet days" to annual averages (Aguilar *et al.* 2005). As a consequence, there are more dry days and precipitation is more variable. These trends are for the region as a whole and there are differences between sites. Changing rainfall patterns could result from altered land use[14] or from climate change. In any case, rainfall changes

[14] Of particular concern is montane deforestation leading to a reduction in water, especially during the dry season (see Figure I-2). Deforestation in the lowland tropics, like that of the overwhelming majority of temperate systems, leads to higher rates of water run-off

and increasing demand for water require proper management of water as a resource. To our surprise, we can find no paper that reviews the importance of water management in terms of biodiversity either for our region or for Mexico as a whole.

Water is especially valuable in the Chiapan highlands. The human population is growing rapidly in both the cities and rural areas. If one looks at an INEGI (Instituto Nacional de Estadística y Geografía) map for the highlands one finds that virtually all streams of any size have been tapped, with blue pipes transporting drinking water to the most populous areas. Like a spider, San Cristóbal de las Casas sits at the center of a pipe web, which can be seen throughout the mountains (Figure I-4). CONAGUA (Comisión Nacional del Agua), the federal commission that engineers the pipes, has a history of solving Mexico's water shortage by finding new water sources rather than concentrating on watershed protection, efficiency, or

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for several years, though water quality worsens (Wohl *et al.* 2012). Similarly, the removal of montane cloud forest decreases water quality, but in some cases it can reduce overall moisture as well as water run-off.

Small aside: the phenomenon of forest loss leading to water loss in unusual montane settings (some high trade wind affected islands, montane forests with large amounts of seasonal fog such as in parts of the US Pacific NW, and certain tropical montane rainforests) has been observed anecdotally for a long time. According to Hayden (1998), the first to note it was Christopher Columbus, as recorded by his son, who witnessed the desertification of the Azores and Canary Islands following the removal of forests by the Portuguese. However, both ancient Greek and Chinese writers mentioned this or at least similar observations—starting at about the 6th Century BCE (N.B., even earlier accounts from both regions portray deforestation in a negative light, though not in relation to water loss). Critias describes deforestation in Attica as leading to a landscape that was like a skeleton, with rainfall no longer being absorbed by the soil, in an incomplete dialogue by Plato (see *Critias* 111 and 117; Platt 1889) (*circa* 360–347 BCE though dating this dialogue is particularly difficult given the fragmentary nature of the remaining text and the characteristic of Plato being difficult to pin down on a timeline). Tzu Chhan attributed a drought in Chêng to deforestation on Mount Sang in about 525 BCE (Needham *et al.* 1996). Still earlier observations likely occurred as ancient civilizations such as the Hani Rice Terraces in China and the Ifugao Rice Terraces in the Philippines are known to have preserved mountaintop forests for water capture (Gu *et al.* 2012).

In any case, the main point of this footnote is to say that tropical cloud forests are unusual in that they have the potential to remain moist with the presence of trees for two reasons. First, their low temperatures mean they have low rates of evapotranspiration. Second, in certain situations they receive high levels of occult precipitation (a combination of vegetation-captured fog and wind-driven precipitation) (Bruijnzeel *et al.* 2011). Where it occurs, occult precipitation's contribution to montane systems tends to be greater during the dry season, reducing overall variability in amounts of water (Bruijnzeel 2004). This likely means that occult precipitation carries added importance for amphibians at that time. Not all loss of natural forest or land use, of course, is equivalent. For instance, turning cloud forests into pasture has different hydrological implications than planting coffee trees, but there is still much to be learned about how water, geology, climate, and land use interact in tropical montane regions (for reviews and further research needs see Bruijnzeel 2002, 2004; Bruijnzeel *et al.* 2011). For discussions of montane forest hydrology in relation to land use in Mexico see Holwerda *et al.* (2010) and Ponette-González *et al.* (2010).

Fig. I-4. CONAGUA's blue pipes carry water throughout the central highlands of Chiapas towards San Cristóbal (left). Burning the land for agriculture in the central highlands of Chiapas along with blue pipes transporting water (right).

water conservation (Montesillo-Cedillo 2006; Muñoz-Piña *et al.* 2008; CONAGUA 2011). In addition, rural populations in the highlands abstract stream water to an amazing degree (Figure I-5). The federal allocation of water has been criticized as unfair (Montesillo-Cedillo 2006) and future shortages and battles over water are a real concern. However, starting in 2010, the federal government has made a concerted effort to identify water reforms that are needed both now and in the near future that specifically deal with issues of governance, water conservation, and efficiency (CONAGUA 2011). The OECD has also reviewed policy reforms for Mexico in the first Country Review on water that the organization has produced for one of its members (OECD 2013). Such reforms are clearly important, but they will be difficult to implement.

Many amphibians are tied to stream habitats. Around San Cristóbal de las Casas, we found *Plectrohyla acanthodes*, a CR frog (see page 201). The greatest threat to this species' existence in the highlands is loss of water flow. Changes to water are a concern for other species as well. *Pseudoeurycea mystax* (EN) in Oaxaca has been found at three localities, one of which is along a river. The river has since been greatly modified and the salamander is unlikely to persist there (see page 167).

Water is a topic that deserves more attention from conservationists and not all aspects of the topic are negative. Mexico's water scarcity can create opportunities for conservation (Muñoz-Piña *et al.* 2008). For instance, the sites we visited are crucial in terms of biodiversity, but some of them also serve as the water source for urban areas so that conserving the site could fulfill a dual purpose (e.g., Cerro de las Flores page 213).

Fig. I-5. Creek bed below Bochojbo Alto, Chiapas. For most of the year a steady stream flows here, but during the winter dry season the flow stops. Locals have constructed a series of dams to hold water and pipe it away from the creek.

Fire

Conservation biologists and ecologists tend to overlook the degree to which fire is a threat to the existence of species. Perhaps this is because fire is known to be a natural process that is necessary for many ecosystems. Indeed, much has been written concerning the detrimental effects fire suppression can have on biodiversity (e.g., Backer *et al.* 2004; Snider *et al.* 2006; Donovan & Brown 2007). In our region the opposite is true. Wildfires are a threat to every AZE site and species. The frequency, intensity, range of habitats affected, and consequences to threatened species from fire have all dramatically increased in recent years—to an unnatural degree. Positive feedbacks from fire, land use, and climate change indicate that the threat of fire will continue to grow.

In addition to being the two most biodiverse Mexican states, Chiapas and Oaxaca have the highest number of fire incidences and amount of burned area annually (SEMARNAT 2002 as cited in Román-Cuesta & Martínez-Vilalta 2006). More than 80% of wildfires here are caused by people (Román-Cuesta *et al.* 2003; Trejo 2008). About 50% of the total represents agricultural or pasture fires purposely set that subsequently become uncontrolled (Román-Cuesta *et al.* 2004; Trejo 2008). They are considered fires of "negligence." Fire as a management tool for

farmers goes back to ancient times. Many experts argue that this method of agriculture is no longer suitable with increasing population growth and shorter fallow periods, but there is little agreement about what the best alternative would look like (Román-Cuesta *et al.* 2003). Another 33% of wildfires are purposely set to become uncontrolled (Román-Cuesta *et al.* 2004). These are termed "deliberate" or "anarchistic," and typically have to do with fires started on the lands of rival communities. This latter cause of fire has increased in recent years (Román-Cuesta *et al.* 2004).

The rising number of wildfires in the region and the fact that they are largely human-caused demonstrates that fire is not in natural equilibrium with the environment. Fire frequency, however, is not an ideal predictor of fire threat to a site. Most fires occur in habitats that require fire and are not "crown fires" (i.e., fires that remove overstory vegetation) (Román-Cuesta *et al.* 2004; Román-Cuesta & Martínez-Vilalta 2006). The fires that are most problematic for threatened species are the relatively few high intensity fires that affect montane forests.[15] These too are increasing in frequency, and the increase is associated with changing El Niño–Southern Oscillation (ENSO) events.

ENSO events are serious threats in their own right. In Mexico, El Niño events typically result in drought, although portions of NW Mexico receive more rain (Magaña *et al.* 2003; Caso *et al.* 2007). The droughts in themselves are probably detrimental to many amphibians. Above we mentioned the less predictable pattern of precipitation generally, and ENSO-related events are one of the contributors, particularly in southern Mexico (Magaña *et al.* 2003). ENSO events have increased in frequency, duration, and severity since 1976 when there was an abrupt shift in Pacific sea surface temperatures, making them warmer compared to the previous 30-year period (Trenberth & Hoar 1996, 1997; Guilderson & Schrag 1998). Of all of the recent El Niño years (1982–83,[16] 1986–87, 1997–98, 2002–03, 2009–10), 1997–98 was the worst in terms of high temperatures, drought, and fire (McPhaden 1999a,b; Trejo 2008).[17] Climate scientists' understanding of the mechanics of ENSO is improving rapidly. However, while it is likely that climate change will affect ENSO, it is unclear what the results will be. Most notably, there is no agreement as to whether climate change is increasing the frequency or intensity of ENSO

[15] Trejo (2008) divided Mexican ecosystems into three groups: fire dependent, fire sensitive, and fire influenced (this latter category is less than 10% of Mexico, and even less of our region). Fire dependent ecosystems are where fire is necessary to maintain ecosystem health (these include pine forests, several oak forests, grasslands, savannas). Our AZE sites tend to be in fire sensitive montane forest areas.

[16] For a detailed review of the biological impacts of this event see Glynn (1988).

[17] During ENSO events in southern Mexico, the dry season is lengthened so that the drought associated with the 1997–98 ENSO year led to massive 1998 fires in what normally would have been the wet season.

events (Collins *et al.* 2010). Since 2000, there appears to have been another shift in Pacific sea surface temperatures, becoming cooler, but it is too soon to know what that will mean for ENSO patterns (Clement & DiNezio 2014). Some authors have suggested that there may be a trend toward a different type of ENSO event (Latif & Keenlyside 2009; Yeh *et al.* 2009).[18] In any case, wildfires are becoming more intense, especially in El Niño years.

Detailed analyses of fire and its effects in the eastern part of our region (i.e., east of the Isthmus of Tehuantepec) have been conducted by Rosa María Román-Cuesta (Chiapas as a whole) and Heidi Asbjornsen (Oaxacan Chimalapas) and their colleagues. Although AZE sites in the rest of Oaxaca fall outside the range of the fire studies, we believe the generalizations we make based on these works are applicable throughout our region. Our Oaxacan sites west of the isthmus have been subject to severe impacts from El Niño fires (see Concepción Pápalo and Sierra de Juárez, pages 91 and 105, respectively) and we have no reason to suspect that these have behaved differently from fires to the east. Largely due to the work of Román-Cuesta and Asbjornsen, we can make a few observations about the importance of ENSO-related fire events.

Southern Mexico traditionally has distinct dry (November–April) and wet (May–October) seasons.[19] In normal years wildfires only occur during the dry season, and the status of vegetation determines the rates of ignition and fire spread (Román-Cuesta *et al.* 2003). This is not the case during ENSO-year droughts when vegetation is water stressed to the point that fire occurrence becomes related to the presence of ignition agents and can take place any time during the drought (Román-Cuesta *et al.* 2003). ENSO-year fires tend to be large, very destructive, and most of them occur in habitats that do not normally have fire (Román-Cuesta *et al.* 2003).

In typical years, fires purposely set for agriculture or pasture spread to higher elevations where they encounter wetter forests that do not burn (Asbjornsen *et al.* 2005) (Figure I-6). During ENSO years, however, such fires are more likely to continue upslope. Two factors make montane forest fires particularly dangerous to AZE species in Chiapas and Oaxaca: 1) AZE sites are small (and often made smaller through deforestation), thus many could be wiped out entirely by a single fire

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[18] For an excellent summary of ENSO see McPhaden *et al.* (2006). Carey and Alexander (2003) have a more introductory discussion, which includes its impacts on amphibians. The best summary of ENSO within the Mexican context is Magaña *et al.* (2003).

[19] The wet summer season also contains a short dry period in July and part of August known as the midsummer drought, or canícula (Magaña *et al.* 1999), which may be increasing in duration and intensity (see Rauscher *et al.* 2008).

Fig. I-6. A typical controlled fire in a predominantly oak forest near Cerro Baúl, Chiapas. In most years, fires such as this one continue burning uphill until they encounter wet forest.

event,[20] and 2) previously burned forests are much more likely to burn in the future and with greater intensity.

There are several reasons why montane forest fires during ENSO events increase the likelihood of future fires of greater intensity. First, forest fires, even some of the most severe, often leave unburned material behind (Figure I-7). This material may be fallen, dead wood, but it can also be standing, living trees. There is a lag time of several years before many trees die following a montane fire, and because of the reduced temperatures at these elevations, lower decomposition rates ensure that the dead woody material remains. Asbjornsen *et al.* (2005) found that four years after

[20] As we were writing this section, we happened to be asked if we knew of any species that had been eliminated in this manner. We do not. We suspect that "good" examples are hard to find anywhere, but that the lack of statistics should not be any reason for complacency. In this regard, we think these fires are similar to the growing threat of climate change in being difficult to point to documented extinctions directly caused by the threat. As it happens, one of us (JFL) had been evaluating Red List species accounts for mammals of New Guinea while working on our project. A clear possibility there would be Telefomin Cuscus (*Phalanger matanim* CR (PE)) that was likely wiped out by fires during the 1998 El Niño (see Leary *et al.* 2008). There are a number of species that have been "close calls." A famous example would be Zino's Petrel (*Pterodroma madeira* EN) at the hands of fire in 2010 (BirdLife International 2012), and we would add *Thorius papaloae* and *Ixalotriton parvus* from our region as a result of the 1998 El Niño fires.

Fig. I-7. Ridge of Cerro Baúl. The top of the mountain was forested until the fires of 1998. Note the large amount of woody material that remains.

the 1998 ENSO fires there was a much higher proportion of deadwood in cloud forest areas that had burned (52–75%) versus those that did not (5–18%). The combination of dead and soon-to-die woody material guarantees a large fuel load for future fires. Second, fires recur in montane areas because once a canopy is reduced the effects of sun and wind dry the soil making it less moist, hence the forest has less hydric protection and is more vulnerable to future fires (Asbjornsen *et al.* 2005). Third, montane forest fires reduce tree species diversity, at least in the short term. This was shown to be the case following fires at both El Ocote Biosphere Reserve and El Triunfo Biosphere Reserve (Trejo 2008). The trees that initially return are more likely to be species that are susceptible to fire. Finally, a point that we have not seen made in the literature (perhaps because it is too obvious) occurs to us as to why fires are more likely to return to a given montane area. That is, because the main driver of fires in ENSO years is the presence of ignition agents, the odds of the same ignition agent striking again in the same place would be higher than random. Remember, most ignition events are caused by negligence or are intentional, and there is no reason to believe that the negligent farmer or rival arsonist is distributed evenly or randomly across southern Mexico.

Climate change

In the previous two sections we discussed some of the changes in Mexico's climate in terms of water and fire. Here we single out climate change and address it directly. Although few species are thought to have gone extinct due to recent climate change, it is currently regarded as one of the greatest challenges facing biodiversity in the 21st century (Leadley *et al.* 2010). Concern about the effects of climate change on species is understandable given the steady stream of alarming statistics appearing in the news. In May 2013, atmospheric CO_2 concentrations exceeded 400 parts per million as a daily average on Mauna Loa volcano, Hawaii—for the highest reading since Charles Keeling began his measurements in the 1950s, and likely representing the highest CO_2 concentrations in three million years (Gillis 2013). Two separate datasets of global temperatures going back to 1850 confirm that all ten of the hottest years on record have occurred since 1997 (Blunden & Arndt 2013), and 2014 was the hottest year on record according to NOAA (2015). Globally, December 2014 marked the 358th consecutive month with a temperature above the 20th century average (NOAA 2015)—meaning that no one under 29 years of age has experienced even an average, let alone cooler than average, month in their lifetime. The Earth is on pace to warm at a faster rate this century (by orders of magnitude) than at any time during the past 65 million years (Diffenbaugh & Field 2013). Such disturbing reports are worthy of the headlines and do not portend well for biodiversity.

Species that live in mountains, both temperate and tropical, are often highlighted as being especially vulnerable to climate change. This is due to the combination of the sensitivity of montane species and the likely exposure that mountains are expected to face (Nogués-Bravo *et al.* 2007). The vulnerability (sensitivity + exposure) of the highland amphibians in our region appears to be high (or perhaps extremely high), but the evidence for this opinion is neither straightforward, nor unequivocal. The classic concern regarding montane species in relation to climate change is that as temperatures rise species will move to higher (hence cooler) elevations, and this cannot continue indefinitely. Because total area is reduced with each step up a mountainside at some point there will be species that run out of suitable habitat. However, the closer one looks at the problem the more complex it becomes.

There has been a trend for species of multiple taxa to move to higher elevations in recent years (Parmesan & Yohe 2003). These upward range shifts correlate with increased temperatures. Yet the trend of upward movement is far from uniform with 25% of species moving downhill (Chen *et al.* 2011). Also, while temperature correlates with the movement trend, there is no mechanistic understanding as to why this occurs for most species. Therefore, it is impossible to say whether the movement is because of temperature or some other factor. Furthermore, few of the studies of elevational range shifts have focused on amphibians (e.g., Raxworthy *et al.* 2008 in

Madagascar), and none have been conducted in or near southern Mexico. Finally, there is some indication that the speed of climate change on tropical mountains is actually slower than in lowland habitats in terms of the distance that a species would have to move to maintain a certain temperature (Loarie *et al.* 2009).[21] Despite these uncertainties and contradictions, there is reason to be concerned about the effects of climate change on amphibians in the region.

One reason to be concerned is because amphibians possess a number of traits thought to make them highly susceptible to changes in climate (Foden *et al.* 2013). Reviews of the impact of climate change on amphibians suggest that while climate change is not a tremendous threat at present, it is likely that it soon will be (Carey & Alexander 2003; Corn 2005). Although amphibians are often described as being sensitive to climate change by virtue of their ties to water at crucial stages of development (for certain groups), physiological requirements, and limited dispersal abilities, they have withstood major climatic upheavals over millions of years (Carey & Alexander 2003; Vieites *et al.* 2007). The worry now is that climate change in the coming century will occur too rapidly for amphibians to evolve, adapt, or avoid its consequences. Thus, even if tropical montane regions face a slower relative pace of climate change (Loarie *et al.* 2009),[22] it could still be sufficiently rapid to cause extinctions.

As a quick aside, the montane amphibians we are concerned with are by definition extremely narrow-ranged and often closely tied to small patches of habitat; they might also have evolved by being poor dispersers that are ill-equipped to adapt to changes in temperature. Janzen (1967) put forward the idea that because seasonal variations on tropical mountains are slight in comparison to temperate mountains, tropical montane species at any given elevation are exposed to a smaller degree of climate fluctuation throughout the year. As a consequence, a temperate species would be more physiologically suited to moving outside their optimal climate to disperse over a mountain pass or to some other portion of a mountain range. That movement by a temperate species would not only have the potential to widen its range, but could result in repeated interchange of individuals making it less likely for specialized species to evolve over time in isolation. Janzen's (1967) hypothesis was meant as a way to explain the high levels of diversity on tropical mountains. In today's world Janzen's idea might explain why montane species are at risk from

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[21] Altitudinal change in temperature, whereby temperature drops with increasing elevation in a regular manner, is called an adiabatic lapse rate. Similarly, temperatures in the lowlands are cooler away from the equator, but this decrease in temperature is much slower (requiring greater distances) than any lapse rate.

[22] Other authors show a high potential for climate change impacts in our region, though usually using other climate factors in addition to average increased temperature (e.g., Beaumont *et al.* 2011).

climate change both in terms of being slow to adapt to abrupt temperature changes and in terms of not being able to move to suitable locations (Rosner 2013).[23]

Most studies of the effects of climate change on species have used two approaches: 1) they look for correlations between population numbers and climate variables over time within a given locality, or 2) they estimate how the geographic range of a species will expand or contract by comparing projected climate change scenarios with models of the climatic parameters a species requires (called the species' "environmental envelope" or "bioclimatic envelope" in a process that is often referred to as niche modeling). We are unaware of the first type of study being conducted specifically for amphibians in our region or anywhere in Mexico, and the second type has only recently been applied.

At present, no study clearly shows the degree to which climate change has affected montane amphibian populations in the Neotropics. The first approach—correlating population reductions with climate variables in a given locality—was taken by Whitfield *et al.* (2007) for La Selva, Costa Rica. Amphibian population numbers over more than a 35-year period correlated with climate-driven reductions in the quantity of standing leaf litter as opposed to disease emergence. Similarly, South Carolina amphibian declines along the Savannah River were shown to be more closely related to changes in climate than to the appearance of chytridiomycosis (Daszak *et al.* 2005). In both cases, however, the direct applicability of the findings to our region is uncertain. Highland species (such as those in our region) are much more likely to be adversely affected by chytridiomycosis than are lowland species (Lips *et al.* 2003a; Smith *et al.* 2009) like those along the Savannah River and at La Selva. Climate change might well be affecting a number of montane species, but the increased susceptibility to disease complicates matters such that lowland studies probably have a very different dynamic.[24]

The one montane study of amphibian declines over time in the Neotropics occurred at Monteverde, Costa Rica (Pounds *et al.* 1999). These authors found correlations between tropical ocean temperature increases, patterns of dry-season mist frequency, and amphibian "crashes" at the tropical mountain site. The authors referred to the loss of moisture as the lifting-cloud-base hypothesis.[25] However, correlation

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[23] Janzen's (1967) hypothesis was not specific to any taxonomic group. For an updated review of the hypothesis, with special emphasis on amphibians and lizards, see Ghalambor *et al.* (2006). For evidence of the reduced range sizes of tropical montane species relative to their temperate counterparts see McCain (2009).

[24] Although Daszak *et al.* (2005) and Whitfield *et al.* (2007) both determined that climate change as opposed to chytridiomycosis was the likely cause of amphibian population declines at their sites, it is worth noting that this interpretation is not universally accepted for either site (see Li *et al.* 2013).

[25] Other researchers have suggested that the lifting of the cloud base might have little to

is different from causation, and other factors, mainly disease, have prevented a straightforward accounting of the effects of climate change on amphibians at Monteverde. Pounds *et al.* (1999) has been influential in forcing people to take climate change on tropical mountains seriously. The authors also recognized that montane frog declines could have been due to chytridiomycosis and suggested several ways in which its effects might be enhanced through an interaction with changing climate variables. In the time since Pounds *et al.* (1999), it has become clear that chytridiomycosis almost certainly caused the collapse of amphibian populations at Monteverde. We discuss the question of whether or not climate change is connected to chytridiomycosis in another section (see Box I-2, 54).

The second approach—modeling future species' ranges in response to climate change—has been attempted for Mexico. A prominent example is Peterson *et al.*'s (2002) study that modeled distributions of 1,870 species under climate change scenarios based on their environmental envelopes. Peterson *et al.* (2002) concluded that few species would be driven to extinction or suffer major contractions in range size by 2055, although the species composition in some places would change dramatically. However, Peterson *et al.* (2002) only considered birds, mammals, and butterflies, and did not include amphibians. Parra-Olea *et al.* (2005b) conducted a similar study for two Mexican highland salamanders that showed they were likely to lose large portions of their range by 2050 due to climate change, and this range loss would be much worse if current deforestation rates continued. Although this latter study is more applicable to our species than the Peterson *et al.* (2002) study, the two salamanders, *Pseudoeurycea leprosa* (VU) and *P. cephalica* (NT), exist outside our region (occurring in central Mexico).

To our knowledge, only Lawler *et al.* (2010), McCain and Colwell (2011), and Ochoa-Ochoa *et al.* (2012) have directly modeled amphibians in our region with a view to their future under change.[26] These studies employed the second approach of modeling amphibian range changes based on their requirements against future projections of climate change. Lawler *et al.* (2010) concluded that rainfall will diminish in southern Mexico between now and the end of the century. This coupled with temperature increases placed amphibian species here into one of the highest two categories (out of 4) of vulnerability to climate change, and they are estimated to have a high turnover in species composition in the future (figures 6 & 3 in Lawler *et al.*

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do with warming oceans (as described by Still *et al.* 1999 and cited by Pounds *et al.* 1999). Rather, they propose the lifting of clouds to be a consequence of regional deforestation in the lowlands (see footnote 8, page 9).

[26] This statement includes an arbitrary distinction in that these are the only studies having any specificity to montane amphibians of the region. Others such as Thomas *et al.* (2004) and Fischlin *et al.* (2007) included some of these species, but as part of large global analyses that are less informative for our needs.

2010, respectively). The geographical extent of Lawler *et al.*'s (2010) study, however, was the entire Western Hemisphere such that details pertaining to amphibians in our region were limited.[27]

From the perspective of amphibians in southern Mexico, McCain and Colwell (2011) give a frightening portrayal of the potential threat from climate change over the coming century. Like Lawler *et al.* (2010), McCain and Colwell (2011) modeled environmental envelopes alongside changes in temperature and precipitation, but they focused on the risk of population extirpations (or the likelihood of a species being pushed out of their environmental envelope on a mountain). McCain and Colwell (2011) built their species' environmental envelopes from records of birds, non-volant mammals, reptiles, and amphibians for a total of 16,848 vertebrate populations across 156 elevational gradients around the world and they compared these envelopes to a range of IPCC regional climate projections.[28] These authors estimated the risk of population extirpation on mountains over the next 100 years due to increased temperature to be about 5% globally (i.e., 5% of populations would be eliminated due to temperature alone). Precipitation, particularly within the tropics, is more difficult to project than temperature and the authors wanted to investigate the degree to which the risk of extirpation would change with the addition of precipitation as a variable. The difficulty of estimating future precipitation translates into greater variability of model results, but on average the added precipitation increased the risk of extirpation 10-fold across all regions (McCain & Colwell 2011).

It is important to remember that the risk of population extirpations as described by McCain and Colwell (2011) for amphibians in our region is often identical to the risk of global extinction for these species. Overall, the authors found that amphibians in Central America (which in this context included our portion of Mexico) were by far at the greatest risk of extirpation relative to any other taxonomic group or to species from any other region. Under the worst case IPCC precipitation projection for amphibians (being driest), the risk of population extirpation was approximately 80%. Salamanders were even worse off with a greater than 90% risk of being eliminated due to climate change (see figures 3 & 4 of McCain & Colwell 2011 where both salamanders under this scenario have >90% risk of extirpation globally (meaning, averaged from all regions) and >90% of Central American

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[27] Each of the two figures in Lawler *et al.* (2010) contains two panels; one for a lower greenhouse gas emissions scenario and one for a higher. In all four maps, it appears as though the highlands of Oaxaca and Chiapas are at risk, but the resolution and size of the figures make it hard to discern into which categories they fall. Lawler *et al.* (2009) contained similar maps for the hemisphere that were more legible (being reproduced in color); however, the relevant amphibian map of turnover in species (figure 3a therein) excluded the highlands of Oaxaca and Chiapas due to "small sample sizes" (pg.593).

[28] McCain and Colwell (2011) used a selection of IPCC regional projections following Christensen *et al.* (2007).

species face the same risk—the combined risk for salamanders in Central America is not explicit in the paper but would be still higher). Wake and Vredenburg (2008) argued that highland salamanders in our region have already declined significantly due to climate change and that extinctions will increase along with rising temperatures. Although these declines have been demonstrated, the cause may not have been due to climate change (see page 45). In any case, Wake and Vredenburg's (2008) warnings about the future are nonetheless consistent with the findings of McCain and Colwell (2011).

Ochoa-Ochoa *et al.* (2012) modeled changes to the geographic ranges of amphibians throughout Mexico at three time periods (2020, 2050, 2080) under a moderate climate change scenario (B2, see footnote 29 page 30). The authors' main investigation was the effects of climate change on the turnover of species across space. However, in terms of extinction risk from climate change, Ochoa-Ochoa *et al.* (2012) used the most established approach that has been applied to species in Mexico to date. Using a large set of museum records, the researchers created niches for each species using Maxent and standard parameters. Their study is representative of what many would consider to be a reasonable projection of what the impacts of climate change will be on amphibians in Mexico over the course of the century. Ochoa-Ochoa *et al.* (2012) estimated that by 2020, 29 amphibians endemic to Mexico will become extinct due to climate change. From 2020–2050 another 14 endemics will disappear and from 2050–2080 two additional extinctions will occur. The authors did not list which species they expected to go extinct or where these extinctions will take place. Instead, they showed maps of the loss of alpha diversity (or species richness per 1 km^2 grid cell) across the country, which suggests that most of the losses to our region would occur in the 2020–2050 time period.

There have been a couple of unconventional climate change studies that are highly relevant to this discussion. Foden *et al.* (2013) also found that amphibians in our region were highly vulnerable to climate change along with several other areas, though to a lesser degree than in the Amazon Basin. Foden *et al.*'s (2013) global study used a slightly different approach from modeled environmental envelopes. Instead of using envelopes, vulnerability to climate change was calculated as a combination of expert opinion about species' ability to adapt and their inherent sensitivity to climate change combined with IPCC climate projections. Foden *et al.* (2013) does not allow for comparisons among taxa because the most climate sensitive species (with the lowest ability to adapt) were selected from each group independently, such that they are only more sensitive relative to others within that particular group.

Another important study produced by Ponce-Reyes *et al.* (2012) estimated the effects of climate change on species within our region. Ponce-Reyes *et al.* (2012),

like Parra-Olea *et al.* (2005b), modeled range losses as being due to both climate change and deforestation. However, Ponce-Reyes *et al.* (2012) did not focus directly on amphibians, but rather on cloud forests throughout Mexico, creating a niche envelope for the entire forest type as if it were a single species. They estimated that 68% of the nation's cloud forest would be lost by 2080 due to climate change. The total losses to cloud forest would be 99% with the addition of deforestation. Because cloud forests contain numerous endemic species, this loss of forest would result in extinctions. In total, Ponce-Reyes *et al.* (2012) estimated that 26 (or 70%) of the vertebrate species endemic to cloud forests will become extinct by 2080. Most of these species are from our region of Mexico and the authors make special reference to one of our sites, Sierra de Juárez, as being a key place in need of protected area status.

We agree with anyone who urges the protection of Mexican cloud forests. However, Ponce-Reyes *et al.*'s (2012) results are a direct consequence of rather extreme assumptions. On the one hand, some of the assumptions are either standard or conservative. For instance, Ponce-Reyes *et al.*'s (2012) choice of emissions scenario, A1B, is often made and the authors make no attempt to factor in possible effects of elevated cloud heights. On the other hand, the assumption that cloud forest can only be lost and never gained—either as a result of range expansion in pursuit of more favorable climate, plot abandonment, or as restoration within current degraded areas—is unrealistic. Cloud forest trees may be poor at expanding or moving as a collective unit, but there is a wealth of species all with different dispersal abilities involved. Likewise, there are bound to be huge differences when it comes to the persistence of plant species under a changing climate, such that block treatment of this habitat type is questionable (see Goldsmith *et al.* 2013). Cloud forest cover has expanded in several parts of Latin America over the past decade (Aide *et al.* 2013); in Colombia, for instance, recovery of cloud forest has been especially impressive (Sánchez-Cuervo *et al.* 2012).

Equally extreme is Ponce-Reyes *et al.*'s (2012) assumption concerning deforestation, whereby all forest that is not currently federally protected will be cut down by 2080. The authors are candid about the need to refine this assumption in the future with socioeconomic modeling of deforestation rates. We agree that further refinement is required. The extreme nature of this model assumption is obvious when one reverses the study's two step approach. Deforestation is added to the analysis after forest losses to climate change. But if we first make the deforestation assumption and take all of the current cloud forest in Oaxaca and Chiapas (total = 11,197 km^2) and remove that which is not in a federal protected area (9,335 km^2), we find an 83% loss in forest solely due to deforestation. Thus the remaining/additional 16% (to equal their estimated 99% loss) lost to climate change that Ponce-Reyes *et al.* (2012) denounce seems unimportant by comparison. In other words, deforestation outside

protected areas drives the model that is supposedly about climate change. Another way to see the extreme nature of this assumption is to look at whether their results are consistent with on-the-ground reality. In the case of Sierra de Juárez, which served as their most dramatic example of species loss, improved forest management has meant that cloud forest is increasing in extent (an impossibility according to the model assumptions) (see discussion of this site, page 105). Finally, while we are strong proponents for protected areas, this part of Mexico may not be easily translated into that conservation paradigm. For example, there are well-managed local protected areas here that appear to be at least as secure as their federal counterparts. Given the historical friction between the federal government and the locals within this site, it is quite possible that the designation of a federal protected area here would result in increased deforestation.

That said, Ponce-Reyes *et al.* (2012) is very important in its support of the cloud forest as a vulnerable habitat. The sensitivity Ponce-Reyes *et al.* (2012) assume is like that of Janzen (1967) with little, or no, allowance for species to move or adapt. There are people who would argue the opposite (following the work of Loarie *et al.* 2009 and Colwell *et al.* 2008) that mountainous species will have the easiest time moving upslope and that the lowland tropics are more vulnerable to climate change. Who is right when it comes to the question of montane species' sensitivity to climate? Much more research is required to answer this fundamental question. Finally, one concrete contribution from Ponce-Reyes *et al.* (2012) that should not be overlooked is the consensus map of cloud forest that is likely to remain in 2080 according to several climate models (their figure S1). Although the science of predicting impacts of climate change has not advanced to the point where we can confidently avoid investment in whole regions of the planet (Tingley *et al.* 2013), we think that we should be prepared to target blocks of forest for protection that are likely to remain. This does not necessarily mean federal protection is essential, rather whatever arrangement that best ensures cloud forest into the future should be pursued.

Studies such as Lawler *et al.* (2010), McCain and Colwell (2011), Ochoa-Ochoa *et al.* (2012), Foden *et al.* (2013), and Ponce-Reyes *et al.* (2012) are useful at a large scale to envision patterns of climate impact, and as we have seen the picture is not encouraging. However, to have confidence about the fate of individual species in relation to future climate change there needs to be model validation. Such validation has been missing from all but a few recent studies (this point has been repeatedly raised in the literature, e.g., McCarty 2001; Araújo *et al.* 2005; Corn 2005; Botkin *et al.* 2007).[29]

[29] Species range modeling in order to understand the possible effects of climate change are now commonly applied to all sorts of taxa in different parts of the world (see Bellard *et al.* 2012). The approach is generally well received although there are a number of conceptual,

Sinervo *et al.* (2010) conducted a rigorous study of the effects of climate change on a set of terrestrial vertebrates in Mexico. They used a modified version of both standard approaches, but their study went a step further. Sinervo *et al.* (2010) surveyed sites for *Sceloporus* lizards from 2006–2008 that had been previously surveyed from 1975–1995. They then constructed climate surfaces based on data from 99 Mexican weather stations for the survey time period. In so doing, Sinervo *et al.* (2010) showed that since 1975 *Sceloporus* lizards disappeared from sites in central and northern Mexico where temperatures had risen during the winter–spring breeding periods. Extirpation risk was greatest in cool montane habitats and for viviparous as opposed to oviparous taxa. Thus, Sinervo *et al.* (2010) had correlations between climate change and species extirpations over time (the first approach above). Sinervo *et al.* (2010) used the second approach of modeling further extirpation in Mexico and other parts of the world, but instead of employing a hypothetical environmental envelope for the lizards, they tested their parameters experimentally (i.e., model validation). Sinervo *et al.* (2010) did this by placing temperature sensors inside lizard replicas at survey sites in two extirpated and extant Yucatan sites for *Sceloporus serrifer* (LC). The data obtained by these physical replicas were used to set parameters for the second approach, allowing them to project extinction rates in lizards similar to Mexican *Sceloporus* on different continents under climate change scenarios with much less uncertainty.

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technical, and practical issues with these approaches. For an excellent summary of the conceptual issues involved see Soberón and Nakamura (2009). For cautionary takes on these models see Dormann (2007) and Jiménez-Valverde *et al.* (2008). For a proponent view see Warren (2012). And for a detailed use of modeling to evaluate the IUCN Red List's ability to accurately assess threats to species due to climate change see Stanton *et al.* (2014).

Some of the criticism of models is that they simplify or ignore biological interactions, which might be more important at determining a species' range than climate variables. Soberón and Nakamura (2009) made a strong case that while this is a limitation it is best to treat biotic factors as being separate in order to allow for a common conceptual framework, language, and the ability to use vast amounts of data that are becoming available.

A few other issues that are important, yet often overlooked, in these models are worth mentioning. Environmental envelopes are built from current species' ranges, which are often imperfectly known. Amphibians are notorious for containing cryptic diversity, thus what is treated as a single species' envelope might have yielded different constraints if in fact the range were composed of multiple species. The current range of the species also might not represent the best envelope, or climatic limitations, for a species if it is already stressed physiologically in parts of the range (e.g., Bernardo & Spotila 2006). Finally, a more technical issue arises in relation to the IPCC projections that modelers test the envelopes against (Beaumont *et al.* 2008). In recent years, these projections have typically followed the scenarios of Nakićenović *et al.* (2000), which served as the basis for the IPCC's Fourth Assessment (IPCC 2007). There have been indications that the middle-of-the-road IPCC scenarios often used by modelers may be on the low end of what we can expect in terms of emissions (Peters *et al.* 2012). The IPCC's Fifth Assessment (released 2013–2014) used new scenarios called Representative Concentration Pathways (RCPs) and we expect that niche modelers will start to use these.

Although the Sinervo *et al.* (2010) study neither occurred within our portion of Mexico, nor included amphibians, it demonstrated that species in the highlands of Mexico are being eliminated by climate change and that many will likely go extinct by 2080. Sinervo *et al.* (2010) also noted that lowland species of *Sceloporus* were replacing or expanding into sites left vacant by extirpated highland species. This, of course, is a problem for the highland species if they are ever to regain lost ground, but it is made worse by the fact that lowland *Sceloporus* tend to be more widespread than the highland species. If the lowland lizards are actually outcompeting the highland species because of climate change there is a worry that this competition will hasten the extinction of narrow-ranging highland *Sceloporus*. Sinervo *et al.*'s (2010) approach of investigating species extirpations at a fine scale is most relevant to amphibians in our area. Further studies, however, are needed to assess whether the effects Sinervo *et al.* (2010) showed for lizards apply to amphibians as well.

Up to this point, every part of this section on climate change skirts around the fundamental question of what amphibians actually do when confronted by climate change. Will they adapt, evolve, move, or go extinct? At present, this remains largely unanswered, but amphibians are not alone in this regard. Despite numerous ways of assessing species' vulnerability to extinction from climate change, we have very little understanding of what the proximate causes of these extinctions will be for any taxonomic group (Cahill *et al.* 2013). It is for this reason that studies such as Sinervo *et al.* (2010), which seek to determine the mechanistic cause of disappearance, are so valuable. Studies such as McCain and Colwell (2011) are also important because they show that average temperature alone is probably not sufficient; in addition to temperature and precipitation, a number of other factors could be important (e.g., increased climate variability as suggested by Vasseur *et al.* 2014).

Researchers' understanding of the capacity of amphibians to tolerate, adapt, evolve, or move in response to near-term climate change is in its early stages. Species' tolerance and adaptation can take many forms, but these are rarely incorporated into models and remain poorly understood for amphibians (as applied to other ectotherms see Deutsch *et al.* 2008; Kearney *et al.* 2009). Microhabitats are particularly important for amphibians (Shoo *et al.* 2011; Scheffers *et al.* 2014), yet they are also difficult to incorporate into models.

There have been a number of documented changes to the timing of amphibian breeding seasons and to phenotypic traits that appear to be linked to climate change. These changes are usually attributed to an adaptive plastic response of individuals or populations rather than to evolution. Thus, despite the hypothesis that climate change will become a huge selective pressure for amphibians (Skelly *et al.* 2007), there has been little or no evidence of evolution in response to anthropogenic climate change for any taxa (Gienapp *et al.* 2008; Merilä 2012). Indeed, some

researchers have estimated the current pace of climate change is more rapid than species can evolve in response (Quintero & Wiens 2013). However, it is extremely difficult to separate plastic phenotypic responses from evolution in the field. For instance, Caruso *et al.* (2014) found that six out of 15 *Plethodon* salamander species (representing different size classes) in the Appalachian Mountains of the eastern US have decreased in size over the past 55 years. Size reduction has been suggested as a universal response to increased temperature brought on by climate change (Daufresne *et al.* 2009), but this is thought not to be a consequence of near-term evolution. Rather, the size reductions in salamanders could be linked to their increased activity and the resulting metabolic expenditures or even a reduction in resources that prevents the salamanders from being able to grow larger (Caruso *et al.* 2014). Yet in this case, the authors did not test for the possibility of genetic changes over time, and it is not clear that this would have even been possible. In any case, given the incredible importance of the question of whether amphibians will be able to evolve in response to climate change more research is needed to test prevailing assumptions (Skelly 2010).

The movement of species to date has often been portrayed in an either–or fashion that assumes either total ease of movement or alternatively no ability to move (e.g., Thomas *et al.* 2004; Fischlin *et al.* 2007). Lawler *et al.* (2013) was one of the first to model movement for different species groups based on "realistic" movement data, but for amphibians such data are limited. Lawler *et al.* (2013) was also useful in that it attempted to map anthropogenic barriers to movement on the landscape. Unfortunately, the analysis of Lawler *et al.* (2013) occurred at too large a scale to be of use in understanding the potential movement of amphibians in our region (each grid cell being 50 km on a side, greater than the total range size of the species we cover). Velo-Antón *et al.* (2013) stressed the importance of dispersal ability, climate, and landscape connectivity for *P. leprosa* (as mentioned previously, a species from central Mexico). It is probably the most relevant study in terms of integrating a montane tropical salamander's movement under future scenarios, but it did not identify specific, anthropogenic barriers to movement such that actions could be taken to increase the species' probability of survival. Future studies would be most beneficial if they modeled realistic movements in a human-dominated landscape (*sensu* Lawler *et al.* 2013), while focusing on regional endemics and weighing the importance of movement and persistence within habitat patches at different time steps (following the example for the western US by Early & Sax 2011). Such studies would be especially useful if they identified actual anthropogenic barriers to movement (that could potentially be removed) and/or key habitats that should be secured.

What can be done about climate change?

There are two main approaches to addressing climate change: adaptation and mitigation. Adaptation involves steps taken to counteract negative effects of climate change, whereas mitigation seeks to reduce the gas emissions that cause climate change. There have been numerous adaptation plans and calls to incorporate climate change into conservation planning (Mawdsley 2011; Morrison & Lombana 2011; Gillson *et al.* 2013), but few expressly consider the needs of amphibians. Shoo *et al.* (2011) provide a summary of climate adaptation measures for amphibians. These authors discuss various approaches of creating artificial microhabitats, restoring or enhancing breeding sites, and adjusting water and moisture at sites particularly at key times of the year. Although these approaches make sense, more testing is required to understand both their efficacy in and application to different regions and species (Shoo *et al.* 2011).

Meanwhile, the case for mitigation grows stronger each day. A common misconception is that much of global warming is already in the pipeline such that the planet will warm in the near term regardless of reductions made to emissions. There is no basis for this notion; reduced emissions would lead to lower temperatures immediately (Matthews & Weaver 2010; Matthews & Solomon 2013). Early mitigation is advantageous from an economic standpoint (Shindell *et al.* 2012; Rogelj *et al.* 2013). Furthermore, early mitigation provides significant benefits to biodiversity (Warren *et al.* 2013). The question is how to get there.

Mitigation can seem overwhelming. Pacala and Socolow (2004) famously put forward an approach to reducing emissions by breaking what seemed like an insurmountable problem into seven wedges—separate slices of the problem that could be attacked simultaneously using current technology, thus making the overall problem seem more tractable. An updated version of this approach makes the case that confronting climate change is still possible, though it is considerably harder now than is usually recognized (Davis *et al.* 2013).

A promising arena in terms of mitigation that benefits biodiversity is the United Nation's Reducing Emissions from Deforestation and Forest Degradation programme (REDD). As previously mentioned (see footnote 8, page 9), deforestation is a major contributor to greenhouse gas emissions (rivaling that of the entire transportation sector). Preventing deforestation is considered one of the most economical ways to mitigate greenhouse gas emissions (Kindermann *et al.* 2009). In addition, the ecosystem services provided by intact forests are exceptional, especially in REDD-eligible developing countries where people are most dependent on natural capital (Turner *et al.* 2007). REDD-eligible areas are also important in terms of housing large portions of the planet's biodiversity. Thus, by using REDD mechanisms the world could greatly reduce the number of extinctions and reduce

atmospheric carbon while directly benefitting millions of people (Strassburg *et al.* 2012). These benefits to biodiversity can be increased further through an additional wildlife premium (Dinerstein *et al.* 2012).

However, REDD and REDD+ (where conservation and sustainable forestry are included along with measures to prevent deforestation) are far from being a panacea for the world's climate change problem. At best it would constitute a single wedge of the problem and could never offset more than a small portion of global fossil fuel emissions (Mackey *et al.* 2013). There are also many technical as well as political hurdles to overcome before REDD becomes part of a binding climate treaty. For instance, caution has been raised about the aspects of REDD dealing with managed timber production (Putz & Redford 2009). That said, there is a chance that REDD will come into force and that it will mark a step forward. Parties to the 2010 Cancun climate meeting introduced REDD as one of the items that will be part of the eventual successor to the Kyoto Protocol. In Warsaw, November 2013, financing tropical countries to prevent deforestation was touted as the only significant agreement among the Parties (Tollefson 2013). We mention REDD because it has real potential, but also because it is an example of how synergistic threats to biodiversity (e.g., deforestation and climate change) can sometimes be addressed in efficient ways.

Chytridiomycosis

Habitat loss is the most prevalent threat to amphibians in Chiapas and Oaxaca, but not the most devastating. Many of the declines experienced by amphibians at the end of the 20th century were deemed "enigmatic" by Stuart *et al.* (2004) because species would simply disappear, even from pristine habitats, for no apparent reason. While enigmatic declines were not associated with as many species as habitat loss and were not witnessed in all parts of the globe, they had greater consequences in terms of rapidly increasing the extinction risk of species. Mounting evidence suggests that these widespread, rapid declines have been primarily due to the emerging fungal disease, chytridiomycosis (Skerratt *et al.* 2007; Lötters *et al.* 2009; Olson *et al.* 2013). Southern Mexico is one of the areas most affected by enigmatic declines. There is little direct evidence implicating disease as the cause of mysterious declines here, and obtaining such evidence might no longer be possible. However, growing circumstantial evidence, and the lack of reasonable alternatives, points to chytridiomycosis as the culprit. In this section, we provide an introduction to chytridiomycosis and its arrival into southern Mexico.

We begin this section with the suggestion that conservation efforts targeting montane areas of Oaxaca and Chiapas would be wise to treat chytridiomycosis as the paramount threat. There are pockets that have escaped the adverse

effects of chytridiomycosis for the time being. There are also frog populations where a few adults persist and even produce tadpoles despite the fact that these offspring are likely unable to mature (metamorphs, the stage between tadpoles and adults, being eliminated by the disease year after year). The amphibians in both of these situations (the as-yet-unaffected-pockets and the demographically-challenged) require swift conservation intervention if we are to prevent mass extinctions. In this section, we give an overview of the disease (for recommendations concerning chytridiomycosis see page 277).

Chytridiomycosis is thought to be the most devastating disease affecting biodiversity (Kilpatrick *et al.* 2010), as well as the most destructive disease that has ever been known to affect vertebrates (Skerratt *et al.* 2007). In 1998, chytridiomycosis was named and linked to amphibian population declines in Central America and Australia (Berger *et al.* 1998). To date, two closely related fungi are known to have the ability to cause chytridiomycosis in amphibians, one of which occurs in Mexico. The first of the pathogens to be described was isolated 14 September 1997 from a captive Blue Poison Dart Frog (*Dendrobates azureus*)[30] at the National Zoo in Washington, DC and formally described as a new species of Chytridiomycota, *Batrachochytrium dendrobatidis* (*Bd*) (Longcore *et al.* 1999).

The second fungal species was isolated from Fire Salamanders (*Salamandra salamandra*) from an affected population in The Netherlands. Martel *et al.* (2013) named the second pathogen *Batrachochytrium salamandrivorans*. The discovery of this second pathogen is such a new development that most of what we know about it is contained in two papers by An Martel and colleagues. From Martel *et al.* (2013), we know that *B. salamandrivorans* shows many similarities to *Bd* both structurally and in terms of how it affects Fire Salamanders. *B. salamandrivorans*, like *Bd*, is also highly pathogenic and able to cause extreme levels of mortality in local populations (pushing these populations to near extinction). There are some notable differences, however, between the two fungi and their effects on amphibians. The structure of *B. salamandrivorans* is similar, but not identical to *Bd*, and it grows optimally in vitro at lower temperatures than *Bd*. Martel *et al.* (2013) tried to infect captive Common Midwife Toads (*Alytes obstetricans* LC) using *B. salamandrivorans*, but the chytrid did not colonize the skin. Because *A. obstetricans* readily develops skin infections when exposed to *Bd*, Martel *et al.* (2013) speculated that *Bd* and *B. salamandrivorans* have different amphibian host specificities.

These findings launched a further investigation into possible disease hosts

[30] Following Wollenberg *et al.* (2006) this species is now considered to be a junior synonym of *Dendrobates tinctorius* (LC) on the Red List (Gaucher & MacCulloch 2010).

and the origins of *B. salamandrivorans*. Martel *et al.* (2014) tested 5391 wild amphibian individuals from four continents for the disease. All of the amphibians testing positive were salamanders. Fire Salamanders from The Netherlands and Belgium tested positive and populations of the species in both countries have shown sharp declines in the wild. The other individuals testing positive came from Asia (specifically, Thailand, Vietnam, and Japan). One Asian newt specimen that tested positive was collected more than 150 years ago. Controlled exposure to the pathogen was conducted on 34 species of amphibians, indicating that salamanders are most susceptible and that some of the Asian species might act as reservoirs for the disease (Martel *et al.* 2014). The rest of this section on chytridiomycosis discusses the disease as caused by *Bd*, which until recently was the only known disease agent and it remains the only one known to occur in our region.

Bd is an unusual pathogen in that it infects a very wide range of hosts (Daszak *et al.* 2000); 516 amphibian species have tested positive for *Bd* (Olson *et al.* 2013). However, host responses to the fungus vary greatly. Species can be entirely eliminated by low levels of *Bd*, while others appear to be entirely unaffected by the pathogen and can act as either reservoirs or vectors for disease. Like any pathogen, the virulence of *Bd* depends upon the classic disease triangle: a dynamic interaction among pathogen–host–environment. Thus, certain environmental conditions can help determine which species are affected (and to what degree) by an outbreak of chytridiomycosis.

Skerratt *et al.* (2007) estimated that approximately 200 amphibian species have shown serious population declines, including probable extinctions, due to chytridiomycosis. Unfortunately, despite wide reference to this number it is quite fuzzy. The main barrier to certainty is that the list of amphibians thought to have declined due to the disease is not necessarily a subset of the species testing positive for *Bd*. The fact is a lot of species disappeared before they could be tested for the pathogen. Thus, it is difficult to be certain which species disappeared due to chytridiomycosis and which disappeared for other reasons. A detailed study of the IUCN Red List by Heard *et al.* (2011) emphasized this uncertainty. However, the uncertainty cuts both ways and it would be presumptuous to assume that the impact of chytridiomycosis on amphibian species has been unduly inflated. Certain species might be considered threatened by chytridiomycosis on the Red List even though they are later found to be unaffected by *Bd* (such as *Plectrohyla matudai* (VU), see Cheng *et al.* 2011) (Figure I-8). Yet many other species, like the two species of Darwin's frogs from southern South America (*Rhinoderma*), are only now having their declines attributed to chytridiomycosis (Soto-Azat *et al.* 2013). In the Mexican context, it is clear that some of the Red List assessors, for species such as *Incilius cristatus*

Fig. I-8. *Plectrohyla matudai* (VU) from Cerro Baúl. Exposure experiments suggest that this species is unaffected by *Bd* and might serve as a reservoir for the pathogen (Cheng *et al.* 2011).

(CR) (Santos-Barrera *et al.* 2010), took a cautious approach by not mentioning chytridiomycosis in the species accounts even though it is hard to imagine a scenario where *Bd* did not play a pivotal role in its decline.

Recent advances in our understanding of chytridiomycosis have opened possibilities about how to manage the disease. Discoveries that some amphibians have innate peptide defenses, commensal bacteria that can actively fight the disease, and/or possible modes of acquired immunity are all exciting areas of research. Although we do not discuss the evidence for acquired immunity in our overview, it is important because it would facilitate the possibility of breeding captive amphibians for resistance/tolerance to the disease. Scientists' understanding of the underlying genomics of *Bd* is also a fast moving topic. It is now apparent that there are several distinct lineages of *Bd* (possibly representing cryptic species) that have geographic signatures and some of these have probably existed for hundreds or thousands of years. We are beginning to understand how *Bd* interacts with its hosts by examining the genes that are triggered when the pathogen is encountered. Finally, another significant finding has occurred by modeling the density dependence of the disease in frogs. This research shows that while complete eradication of chytridiomycosis from an area must still be

viewed as impractical, there is reason to be optimistic that the disease could be managed in wild populations of amphibians.

Bd infects parts of amphibians containing keratin. Frogs and salamanders have keratin in their skin, and it is here that *Bd* attacks. *Bd* is an aquatic fungus with two distinct life stages: 1) a motile zoospore that propels itself through water using a flagellum and encounters amphibian skin,[31] and 2) the zoospore embeds itself in the amphibian skin and forms a spherical thallus, which matures into zoosporangia and asexually reproduces to release motile zoospores via discharge tubes to water.[32] The degree of complexity *Bd* exhibits when infecting hosts and releasing zoospores indicates that it has a long evolutionary history of infecting amphibian skin (Berger *et al.* 2005a). The skin of amphibians serves a crucial osmoregulatory function allowing the exchange of respiratory gases, water, and electrolytes between the organism and the environment. *Bd* kills amphibians by inhibiting the exchange of electrolytes across the epidermis, ultimately leading to cardiac arrest (Voyles *et al.* 2009).

Tadpole skin does not contain keratin; however, the mouthparts of many species are hard and highly keratinized. *Bd* only infects tadpole mouthparts, and tadpoles of most species are relatively unaffected by *Bd*. Tadpole feeding might be somewhat affected, but *Bd* tends not to cause mortality in tadpoles even in species where adult frogs are vulnerable to the disease. Daszak *et al.* (1999) raised the possibility that tadpoles serve as reservoirs for the pathogen. This would explain some of the destructiveness of chytridiomycosis because a reservoir would allow the pathogen to be maintained in the environment to infect individuals even when the density of adults was low. Berger *et al.* (1998) noted that tadpoles were present at sites in Australia and in Central America after the adults had disappeared. Because some of the tadpoles of frog species in southern Mexico survive for a couple of years, tadpoles in many cases might be the best way to locate remaining frog species. As tadpoles develop into metamorphs, the skin becomes keratinized and *Bd* is able to spread over the animal (Marantelli *et al.* 2004; Rachowicz & Vredenburg 2004). Metamorphs of frogs are often highly susceptible to *Bd* (Lamirande & Nichols 2002; Woodhams & Alford 2005)—though not always, see Savage *et al.* (2011). This means

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[31] Evidence of positive chemotaxis by *Bd* to nutritional cues, including components of keratin, suggests that zoospores are drawn to amphibian skin (Moss *et al.* 2008), which means that zoospores might be capable of swimming farther than previously thought (a possibility put forward by Piotrowski *et al.* 2004, but one that they were unable to substantiate).

[32] Some authors consider the life history of *Bd* to consist of three distinct stages, where the second stage, as we have depicted it, is divided in two (e.g., Daszak *et al.* 2007). Other authors interpret the life history of *Bd* as being four distinct stages (e.g., Rosenblum *et al.* 2010a). A two-stage description, however, captures the main features (Voyles *et al.* 2011).

that there are likely situations where a few adults survive to reproduce, but the tadpoles are unable to mature into adulthood. In such cases, tadpoles could be seen for years following *Bd*'s arrival, but the population would be unsustainable. Scott (1993) made the first observation of this phenomenon, calling it "postmetamorphic death syndrome" in an amazingly prescient piece that outlined the reasons why a new disease might be responsible for mass die-offs in the western US, which we now know as chytridiomycosis.

Temperature and moisture influence *Bd* growth and survival, and prevalence of the disease has been shown to vary seasonally in many affected areas (Berger *et al.* 2004; Retallick *et al.* 2004; Longo *et al.* 2010; Kinney *et al.* 2011). *Bd* cannot withstand desiccation (Johnson *et al.* 2003), or is at least poor at tolerating it (Garmyn *et al.* 2012). In culture, it grows and reproduces within a wide range of temperature and pH: 4–25°C at pH 4–8 (with optimal reproduction at 17–25°C and pH 6–7) (Piotrowski *et al.* 2004). Interestingly, however, Raffel *et al.* (2013) have shown that *Bd* growth on living frogs in response to temperature is actually opposite to *Bd* grown in culture. Thus, in culture, *Bd* grows better at 25°C than 15°C, whereas on a frog, *Bd* grows better at 15°C. The pathogen ceases to grow at 28°C, and perishes at 30°C, but death takes a number of days (50% of replicates died in 8 days) (Piotrowski *et al.* 2004). Southern Orange-eyed Tree Frogs (*Litoria chloris* LC) housed in an enclosure at 37°C were cleared of the pathogen within 16 hours, and slightly lower temperatures for longer periods might have the same effect (Woodhams *et al.* 2003). *Bd* has been found in cold regions, at 5244–5400 m asl in the peaks of the Ecuadorian and Peruvian Andes (Seimon *et al.* 2007) and in Canada's Northwest Territories (Schock *et al.* 2010).

Bd has yet to be shown to conclusively remain in the environment for long periods in the absence of amphibian hosts (Rosenblum *et al.* 2010a). The fungus can persist in sterilized lake water in the laboratory for up to seven weeks (Johnson & Speare 2003), it has been detected in natural water bodies (Kirshtein *et al.* 2007; Walker *et al.* 2007), and, with important implications for our region, it has been detected in the water of bromeliads in Ecuador (McCracken *et al.* 2009). The possibility that *Bd* can exist for long periods without amphibians is heightened by the fact that it can be found on waterfowl (Garmyn *et al.* 2012) and reptiles (Kilburn *et al.* 2011)—both of which might serve as vectors as well as reservoirs. McMahon *et al.* (2013) have gone a step further demonstrating that *Bd* cannot only be found in non-amphibian hosts (i.e., crayfish), but that it can grow and subsequently be transmitted to amphibians.

Although the basic life cycle of *Bd* and how it kills amphibian hosts are

understood, there are many unanswered questions. Chief among these is, *Why are some amphibian species devastated by Bd, while others remain unaffected?* Certainly environmental conditions are a major factor in the prevalence of chytridiomycosis. Although chytridiomycosis affects amphibians in the warm lowlands (Whitfield *et al.* 2012), even with mortality (Fisher *et al.* 2009a), it is cool montane habitats in the tropics that have been most severely affected (Berger *et al.* 1998; Lips *et al.* 2003a, 2005). These habitats are better suited to the growth of *Bd*, and the amphibians in these settings might be more susceptible to the disease. Increased susceptibility could be due to a lowered immune response of hosts at reduced temperatures (Carey *et al.* 1999) or genetic differences between typical lowland and highland species. At present, the balance of evidence does not support the increased susceptibility argument.[33] However, differential acclimatization of amphibians and *Bd* to sudden changes in temperature might create a scenario that favored *Bd* infections at higher elevations (see Box I-2, page 54).

Amphibian skin is continually being invaded by microbes and amphibians have several defenses against them. Some amphibians produce skin peptides that either attack or inhibit the growth of *Bd* (Rollins-Smith & Conlon 2005; Rollins-Smith *et al.* 2011). Such innate defenses vary between species (Woodhams *et al.* 2007a). Peptide defenses are considered innate because an individual amphibian that produces them does so without any prior encounter with (or recognition of) the pathogen.

Warding off *Bd* might also vary among amphibian species due to differing abilities to guard against immune-suppressing chemicals emitted by the pathogen. Fites *et al.* (2013) separated *Bd* from amphibian splenocytes (cells that contribute to the immune response of the host) using a cell-impermeable membrane (preventing zoospores and zoosporangia from direct contact with the splenocytes). The presence of zoosporangia, but not zoospores, induced apoptasis in the amphibian cells, which suggests that a chemical factor released by zoosporangia could impair an amphibian's immune response to *Bd*. Interestingly, Fites *et al.* (2013) found that the chemical factor was resistant to protease and reduced by nikkomycin Z. This, coupled with the fact that zoospores, unlike zoosporangia, do not have cell walls, suggests that the chemical factor consists of cell wall material similar to other known fungal immune suppression mechanisms. Ellison *et al.* (2014) have shown

[33] Lowered immune response at higher elevation has been put forward as a contributing factor, but if this were the case one would expect to find amphibians succumbing to a combination of diseases. Amphibian necropsies instead show that chytridiomycosis alone often kills (Berger *et al.* 1998, 2004). Also, genetic differences between lowland and highland species is tenuous because some species (e.g., three EN species: *Litoria dayi, L. nannotis*, *L. rheocola*) are known to disappear only above a certain elevation (approximately 400 m for the species mentioned) (McDonald & Alford 1999).

that immunosuppression can occur following the activation of genes that would otherwise mount a defense against *Bd*. Further *in vivo* experiments indicate that *Bd* inhibits immunity (Young *et al.* 2014; Fites *et al.* 2014). The new focus on *Bd* immunosuppression might help to explain why some amphibian species are less susceptible than others to chytridiomycosis.

Another reason species could differ in susceptibility to disease is due to differences in naturally occurring bacteria on amphibian skin which inhibit *Bd* growth (Harris *et al.* 2006). The presence of beneficial bacteria, for instance, has been put forward as a possible reason why some lowland *Atelopus* species survive in the presence of *Bd* (Flechas *et al.* 2012). This is particularly exciting because the presence of the bacteria is not necessarily species specific—some individuals of a species can have the anti-*Bd* bacteria while others do not.[34] Further laboratory testing, whereby amphibians were inoculated with anti-*Bd* bacteria, confirmed that the commensal bacteria could be introduced and prove effective in the fight against chytridiomycosis in frogs (Harris *et al.* 2009a) and salamanders (Harris *et al.* 2009b). There is a possibility that adding beneficial bacteria to wild amphibians could be used as an *in situ* management tool for some species as a means to ward off the disease or as a tool to increase the efficacy of reintroductions (Woodhams *et al.* 2011; Bletz *et al.* 2013). We discuss bioaugmentation further in another section (see Recommendations, page 287).

Initial molecular studies of *Bd* showed that the pathogen contains low levels of genetic diversity, high levels of heterozygosity, and an obscured geographic structure (Morehouse *et al.* 2003; James *et al.* 2009). This supported the hypothesis that *Bd* has recently spread to many corners of the Earth, most likely with human assistance (Fisher *et al.* 2012). However, the geographic origins of *Bd* are unclear. Authors have suggested that *Bd* could have spread from Africa (Weldon *et al.* 2004), Asia (Goka *et al.* 2009), North America (James *et al.* 2009), or South America (Rodriguez *et al.* 2014). This is particularly hard to determine given that there has been relatively sparse sampling for *Bd* in Africa and Asia, and most sampling that has occurred around the globe has been targeted in areas affected by disease (Fisher *et al.* 2009a; Rosenblum *et al.* 2010a,b). There have been recent efforts to increase sampling for *Bd*'s current distribution in Asia (e.g., Swei *et al.* 2011) and its historical occurrence in Africa (e.g., Soto-Azat *et al.* 2010). While these efforts improve our understanding of the distribution of *Bd*, more information about the genomics of *Bd* will be

[34] Above we noted the greater severity of chytridiomycosis at higher elevations on individuals of the same species. We wonder if this could be due to impoverished microbial communities at higher elevations that might otherwise disrupt *Bd* growth—a possibility that we have not seen raised in the literature.

necessary before its origins can be determined. At this point, *Bd* is known to be non-native to many areas, yet evidence for a deeper evolutionary association with amphibians and endemic lineages with what appear to be different geographical signatures indicate that there is unlikely to be a single, modern day point of origin.

One of the major findings from recent genomic research is that *Bd* is much more diverse than previously thought. Farrer *et al.*'s (2011) study of population genomics from 20 *Bd* isolates (from five continents) has further bolstered the view that *Bd* has recently spread to most of the places where it occurs. More importantly, this study increased our understanding of the pathogen in terms of its genetic structure and disease epidemiology. Farrer *et al.* (2011) identified three separate lineages of *Bd*: 1) *Bd*-GPL, the "global pandemic lineage" that is associated with each of the regional epizootics in Europe, North and Central America, Africa, and Australia, 2) *Bd*-CAPE, the "Cape lineage" from South Africa that was accidentally introduced to Mallorca, Spain, and 3) *Bd*-CH, the "Swiss lineage" that occurs in several places in Europe.[35] There is a fourth lineage that has been reported from Japan, China, and India (Goka *et al.* 2009, Bai *et al.* 2012, Dahanukar *et al.* 2013, respectively). There is also a fifth lineage that has been reported from Brazil (Schloegel *et al.* 2012; Rosenblum *et al.* 2013). One or more of these *Bd* lineages could be endemic (in the epidemiological sense) to their given region. It is also likely that more lineages will be discovered. Researchers are using increasingly sophisticated techniques to reveal greater genetic variation than was previously thought possible even within the *Bd*-GPL (Rosenblum *et al.* 2013). Variation within and among lineages has consequences. *Bd* isolates have been known to differ in terms of their morphology, quantity of zoospore production, and pathogenicity (Berger *et al.* 2005b; Retallick & Miera 2007; Fisher *et al.* 2009b; Voyles 2011). Farrer *et al.* (2011) found that pathogenicity differed greatly between lineages, and that *Bd*-GPL was the most pathogenic. Furthermore, there were differences in pathogenicity even within *Bd*-GPL (Farrer *et al.* 2011).

Thus far, only *Bd*-GPL has been found in Mexico and studies to date suggest that it is a novel pathogen. Velo-Antón *et al.* (2012) have shown that *Bd* isolates from California to Panama are genetically similar (to the extent that supports *Bd* being a novel pathogen to Mexico and Central America). These *Bd* isolates, however, exhibit a spatial pattern with regards to their levels of heterozygosity. Isolates to the south are progressively less diverse than in the north (Velo-Antón *et al.* 2012), which is what one would expect if *Bd* had spread from north to

[35] Farrer *et al.* (2011) suggest that the separate *Bd* lineages might represent cryptic species. Rosenblum *et al.* (2013) agreed, but state that more sampling is required before that can be determined.

south (either because of rapid asexual reproduction along the invasion front [James *et al.* 2009] or because of genetic bottlenecks that occur as the pathogen moves into new territory [Clegg *et al.* 2002]). Cheng *et al.* (2011) provided evidence of such a spread and its timing (with *Bd* first arriving to southern Mexico in the early 1970s and then appearing in Guatemala in the 1980s). Cheng *et al.* (2011) did so by developing a new technique to examine museum specimens for the presence of *Bd* spores. By testing MVZ specimens from southern Mexico, Cheng *et al.* (2011) could show that no Mexican specimen collected prior to 1972 (1974 for our region) tested positive for *Bd*, but from 1972 onward *Bd* increased in prevalence. Cheng *et al.*'s (2011) findings show that the timing of *Bd*'s arrival to our region corresponds to reported frog and salamander declines.

In 2000, Lips *et al.* (2004) conducted population surveys for frogs along the same transects in Oaxaca used by Janalee Caldwell from 1969–1970 and in several localities in Chiapas. They reported population crashes at all survey localities and the possible extinction of certain species. Lips *et al.* (2004) attributed these declines largely to chytridiomycosis because they had just found dead frogs in Guerrero that had been infected with *Bd*, mouthparts were missing from tadpoles in Oaxaca and Chiapas, and the population declines they documented were incredibly severe from within undisturbed habitat (Lips *et al.* 2004). Steep declines at some time since the 1970s and 1980s have also been shown for salamanders at Cerro San Felipe (Parra-Olea *et al.* 1999; Rovito *et al.* 2009b) and the Sierra de Juárez transect along Highway 175, Oaxaca (Parra-Olea *et al.* 1999) (collectively these two areas correspond to our Sierra de Juárez AZE site, see page 105).

Massive amphibian declines and the presence of *Bd* do not necessarily mean that *Bd* is the cause of the declines (McCallum 2005). Ochoa-Ochoa *et al.* (2009:6) made this point when they stated that amphibian populations have been known to disappear in Mexico because of deforestation, but "although the presence of the fungus has been reported, there is no demographic study that confirms amphibian population decline caused by the fungus." Similarly, Rovito *et al.* (2009b:3234) concluded that while chytridiomycosis "may potentially have played a role," proof connecting *Bd* to salamander declines was lacking.

Rovito *et al.*'s (2009b) work documenting salamander declines in Guatemala and southern Mexico was inconclusive as to its cause. Rovito *et al.* (2009b) found *Bd* on seven of the 62 salamanders they collected from 2005–2007. All seven individuals with *Bd* were from Guatemala and none of them represented species that had undergone population crashes (4 were from an abundant

lowland species and 3 were from stable high elevation species). After reporting these findings, Rovito *et al.* (2009b) dismissed chytridiomycosis and turned to climatic factors that they believed to be more likely drivers of the declines.

Rovito *et al.*'s (2009b) findings, however, are consistent with what one would expect from a chytridiomycosis affected area. McCallum (2005) made three predictions for host–parasite interactions in relation to frogs and *Bd*, which are equally applicable to salamanders. McCallum (2005) stated:

> "If other frog species are acting as reservoirs, we can make the following testable predictions. First, although the fungus may not be entirely benign in reservoir nondeclining species, it should be less pathogenic in these species in the conditions under which they normally live than in species that have declined. Second, where species that have declined still exist, *B. dendrobatidis* should occur at lower prevalence in the endangered species than in sympatric reservoir species. Third, chytrid-infected reservoirs should still exist at sites where endangered species have either declined or disappeared." (pg.1425)

The first and third predictions from McCallum (2005) match Rovito *et al.*'s (2009b) report of *Bd* from common non-declining species. The second prediction—that the declining species should have a lower prevalence of *Bd* (presumably because those that were infected would quickly die before detection)—could explain why none of the individuals from declining species tested positive for *Bd* in Rovito *et al.*'s (2009b) study. Therefore, while the findings of Rovito *et al.* (2009b) did not show chytridiomycosis as a major cause of amphibian declines, their results are compatible with that scenario.

The ideal proof for devastating declines from chytridiomycosis would be to sample amphibians for *Bd* in a field site before, during, and after an outbreak. If we are correct that most of southern Mexico has already been affected by the pathogen, then such a line of evidence is unlikely to still be possible. That said, it is not difficult to see the relevance of recent developments in the study of chytridiomycosis. The pattern of chytridiomycosis spread from southern Mexico to Guatemala described by Cheng *et al.* (2011) is one piece of a larger progression southward that has been identified by Karen Lips and her colleagues.[36] This

[36] Work to identify the earliest evidence for *Bd* in the region continues. For example, it is now thought that *Bd* arrived in Guatemala as early as 1980 (Mendelson *et al.* 2014), which explains the first accounts of frog disappearances in the area (e.g., from the early 1980s, see Mendelson 2004) and tadpoles' missing and/or deformed mouthparts (e.g., from 1989, see Campbell & Smith 1992).

progression is informed by two landmark studies (one in Panama, Lips *et al.* 2006, and one in the US, Vredenburg *et al.* 2010), each of which tracks *Bd*'s arrival at a location all the way through an outbreak.

In addition to documenting dramatic frog declines in southern Mexico, Karen Lips witnessed population crashes in Costa Rica from 1991–1996 (Lips 1998) and in Panama from 1996–1997 (Lips 1999). The site in Panama was Reserva Forestal Fortuna, Chiriquí and Lips reported clinical evidence of a fungal disease of the skin and abnormal mouthparts in tadpoles similar to what she had found in Las Tablas and Monteverde, Costa Rica. The population crashes were severe at all three of these sites, but at this point the disease had not been formally described. When these and additional declines for Costa Rica and Panama were mapped they appeared in a wave-like fashion with areas being infected first in NW Costa Rica and progressing eastward into Panama (figure 1 in Lips *et al.* 2003b).[37] The mapped progression of amphibian die-offs was appealing as an explanation, but it was not definitive and no one knew whether or not *Bd* was present at the sites prior to the population crashes. For instance, if *Bd* had always been present or its arrival was inconsistent with the timing of the declines, then it would be unlikely to be the main driver of the declines without some other mitigating factor.

Lips *et al.* (2006) sought to address these questions. At El Copé, Panama, Lips and her colleagues captured 1,566 individuals of 59 species from a healthy Neotropical forest at regular intervals prior to October 2004. They tested these individuals for *Bd* and found none. In October 2004, *Bd* appeared along with population declines. All told, Lips *et al.* (2006) found 346 frogs (of 38 species) and five salamanders (of 3 species) between October 2004 and February 2005 that had died from chytridiomycosis (another 9 species of frog and 1 salamander species tested positive for *Bd* using polymerase chain reaction (PCR) assays of swabs). El Copé, Panama was just one stop along the way as *Bd* continued its progression from Costa Rica towards South America (Lips *et al.* 2008; Woodhams *et al.* 2008).[38]

This progression has proven to be devastating in terms of population

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[37] Laurance *et al.* (1996, 1997) described a similar wave-like progression of amphibian die-offs moving through Australia. At the time, chytridiomycosis was undescribed, but Laurance *et al.* (1996, 1997) concluded that it was likely due to a highly virulent waterborne pathogen, which is now commonly presumed to have been *Bd* (see Berger *et al.* 1998).

[38] Although chytridiomycosis has not yet reached South America via Panama, the disease has been reported from numerous locations across the continent. *Bd* is thought to have been introduced to multiple countries starting in 1970s (Lips *et al.* 2008), although *Bd* has been present in the Atlantic Forest of Brazil for at least a century and could possibly have originated there (Rodriguez *et al.* 2014).

reductions. Smith *et al.* (2009) compared pre- and post-chytridiomycosis amphibian survey results for eight sites in Costa Rica and Panama and found an average 42.4% reduction in the number of amphibian species at a site (range: 33.3–65.0% reduction). These are extraordinary numbers. To give some perspective to them, consider that foot-and-mouth disease (FMD) ranks first on the World Organization for Animal Health's (OIE) A-list of infectious animal diseases (Sobrino *et al.* 2001) and is rated as the second most dangerous disease threat to animal agriculture by the US government (highly pathogenic avian influenza is first and it has a mortality rate that varies widely with strain; NVS 2009). FMD's mortality rate in an outbreak affecting adult cloven-footed livestock is typically around 1%; it is higher in juveniles and can reach 50% under extreme circumstances (Barnett 2003; USDA 2013). This is considered catastrophic, yet with chytridiomycosis we are talking about 100% elimination of upwards of half the species present at the time of an outbreak. In some cases, this means more than 30 species are extirpated from a site (Smith *et al.* 2009); we typically do not mention population reductions within the remaining species. Moreover, the reductions are non-random, disproportionately eliminating endemic species—reducing phylogenetic diversity as well as beta-diversity, and ultimately resulting in a rapid homogenization of the amphibian fauna (Smith *et al.* 2009; Crawford *et al.* 2010).

Vredenburg *et al.* (2010) conducted a similar study to Lips *et al.* (2006) in advance of *Bd* in populations of *Rana muscosa* (EN) and *R. sierrae* (EN) in the Sierra Nevada mountains of California, USA that confirmed suspicions of *Bd* as a novel pathogen to the region. Vredenburg and colleagues went a step further than Lips *et al.* (2006) by using real-time quantitative PCR counts of *Bd* load of individual frogs before (when they tested negative for *Bd*) and during the invasion of *Bd* that led to population crashes, allowing for the measurement of infection intensity (measured as the number of zoospore equivalents per swab). In this study, frogs in the three basins covered were expected to be entirely wiped out by the disease with the arrival of the pathogen. Total elimination of these frogs, however, is not a given (Briggs *et al.* 2005).

Briggs *et al.* (2010) modeled the density dependence of *R. muscosa* and *R. sierrae* in relation to *Bd* and found that they could explain the survival of some of these frog populations without invoking host susceptibility, *Bd* pathogenicity, or environmental conditions. *Bd* levels increase rapidly when host density is high because more amphibians are available for the production of zoospores, which are then released to the environment. Once a threshold is reached whereby high numbers of spores surround each frog, the population begins to crash. Because the density of frogs is at its greatest just prior to the arrival of *Bd* to a naïve population, individuals in such a population are the most likely

to be wiped out by the disease. If some individuals, however, survive that first wave and the levels of *Bd* in the environment go below the threshold, these remaining frogs are able to survive infections. Briggs *et al.* (2010) found that frogs surviving an initial wave would routinely become infected and clear the disease multiple times afterward. The post-wave adult frogs showed a high prevalence of the disease, but the *Bd* loads were much lower than in individual frogs during the initial wave, and an infected frog in a post-wave setting was no less likely to persist than an uninfected frog (Briggs *et al.* 2010).[39] The density dependence model suggests that reducing either the amount of *Bd* in the environment and/or the number of hosts could be a useful management approach.

We have emphasized the density dependence model for frogs in the Sierra Nevada mountains because it is likely to apply to other regions. Working in Mallorca, Spain, Jaime Bosch removed all individuals of Mallorcan Midwife Toad (*Alytes muletensis* VU) from ponds that were known to have *Bd*.[40] Bosch then drained the ponds with the intention of killing the fungus. He further sought to clear all the tadpoles of *Bd*. The tadpoles were reintroduced to the ponds the next season. To Bosch's surprise, the toads in the pond tested positive for *Bd* later in the season. More surprising still was the fact that individuals were surviving at a much higher rate than in previous years. Bosch wanted to demonstrate that *Bd* could be eliminated from wild populations, but instead he concluded that reducing *Bd* loads led to increased survivorship for *A. muletensis*. It is likely that reducing *Bd* below the threshold where it kills is one of the keys to managing chytridiomycosis in wild populations generally (Briggs *et al.* 2010; Vredenburg *et al.* 2010).

Although the density dependence model opens many possibilities and likely has broad applicability, it does not appear sufficient to describe the dynamics of every system. Earlier in this section, we discussed the importance of the question, *Why are some amphibian species devastated by Bd, while others remain unaffected?* A variant of this question is, *Why are some individuals of a species severely affected when others are not?* The density dependence model explains part of this for frogs in the Sierra Nevada mountains, but it fails to answer why certain individuals survived the initial wave of *Bd*. The authors of the density dependence model are keenly aware of this puzzle and have pursued several possibilities (see Vredenburg *et al.* 2011). The model also appears to be inconsistent

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[39] The post-wave survival rates for infected individuals probably varies. Murray *et al.* (2009), for instance, found that chytridiomycosis reduced monthly survival of *Litoria pearsoniana* (NT) by approximately 38% in a study site in Queensland, Australia, but the species still persists 30 years after *Bd* arrived.

[40] A news story by Lubick (2010) served as the basis for this paragraph.

with results from some of the recent studies of post-wave *Bd* populations.

There have been a number of studies of post-wave population outcomes. Most of these studies depict populations (or individuals from certain species) that tolerate the disease such that it has little effect, are wiped out by it, or hang on at low levels. Increasingly, however, there is evidence of populations of highly susceptible species that are now increasing in size and/or expanding in range (Tobler *et al.* 2012; Newell *et al.* 2013; Scheele *et al.* 2014). Coupled with these encouraging findings is the recognition that while *Bd* becomes ubiquitous when it enters a region for the first time, some areas where it has existed for long periods show seemingly inexplicable gaps in presence (Strauss & Smith 2013).

In each of these settings, authors have put forward various biotic and abiotic factors to explain unexpected host survival and/or gaps in *Bd* presence. These factors have different levels of supporting evidence and breadth of applicability. Here is our list with a few notes on each; more possibilities are likely to appear in the future.

Reasons for susceptible individuals or a population to survive a wave of *Bd*:

- Random – individuals were missed/lucky when the first wave hit. We have not seen this explicitly raised by any author, but the law of large numbers and random elements introduced by transmission and propagule pressure support the possibility that a few individuals happened to be in the right place for just enough time.
- Behavioral differences between individuals – some frogs seek drier microclimates, bask in the sun, or induce fever as a means to temporarily reduce risk of infection (Hossack *et al.* 2013). Although this mechanism has not been applied specifically to the avoidance of an initial wave of *Bd*, there is no reason it would not apply.
- Environmental refuges (meaning either temperature or moisture) – individuals of a species might be better able to withstand *Bd* if they happen to reside in otherwise suboptimal habitats (drier and/or hotter). From a hypothesis standpoint this is essentially the same argument as the previous one, concerning behavioral differences between individuals, but applied over a larger scale whereby the individual presumably did not choose the suboptimal habitat. Moreover, some authors believe individuals of susceptible species in these refuges can be located using predictive habitat models (like those described earlier for climate, see page 26). To date, identification of environmental refuges are credited with helping to rediscover species that were thought to be

extinct, yet the efficacy of the models has not been formally tested (see Puschendorf *et al.* 2009, 2011; Woodhams *et al.* 2011; García-Rodríguez *et al.* 2012).

- Skin microbes – mentioned previously with regard to differences between species. In the context of the Sierra Nevada mountains, some populations of *R. muscosa* might be more likely than others to survive an initial wave of *Bd* because individuals in those populations harbor higher loads of beneficial skin bacteria (Woodhams *et al.* 2007b). An expanded study found a correlation between bacterial load and amphibian survival in *R. muscosa* (Lam *et al.* 2010).
- Skin peptides or other innate immunity – mentioned previously in relation to differences between species. Perhaps individuals of a species also vary in this regard.
- Interaction between beneficial microbes and peptides – together these might produce the right circumstances for individuals to resist severe infection (Myers *et al.* 2012).
- Acquired immunity – some portion of the host population might have a genetic difference that makes it able to survive. Acquired immunity in amphibians is controversial (for a review see Venesky *et al.* 2014a). As recently as 2010, Stice and Briggs (2010:75) concluded that "there is no evidence to date that adaptive immunity plays any part in resolving chytrid infections." However, it is now clear that multiple species can overcome infections or use behaviors to reduce *Bd* loads with increasing effectiveness related to the number of prior exposures (McMahon *et al.* 2014). Presumably individuals of a species could also vary in the degree to which they show evidence of acquired immunity.
- Presence of tiny *Bd* predators – this is thought to influence whether or not *Bd* can persist and thrive at a site. Strauss and Smith (2013) have shown that the composition of zooplankton in ponds without *Bd* are more alike than expected by chance and that they differ in this respect from otherwise similar ponds testing positive for *Bd*. Thus, by extension, a population of susceptible amphibians might be spared given the right combination of zooplankton at a localized scale. Planktonic *Daphnia* species consume *Bd* (Buck *et al.* 2011; Hamilton *et al.* 2012). Woodhams *et al.* (2011) put forward the idea of possibly adding *Daphnia* to freshwater systems to reduce numbers of *Bd* zoospores. However, *Daphnia* is one of many possible *Bd* predators. Schmeller *et al.* (2014) demonstrated that when *Bd* was added to lake water from the Pyrenees with low *Bd* prevalence it quickly perished compared to lake water where *Bd* regularly occurred. These authors found that three

species of microscopic predators were consuming *Bd* zoospores, but they were quick to point out that these are probably not the only ones; indeed, they stated, "microorganisms able to prey on *Bd* zoospores are expected to be numerous" (Schmeller *et al.* 2014:179).

- Presence of other amphibians that dilute effects – experimental evidence for this has been shown in mesocosm studies of tadpoles whereby the addition of certain tadpole species reduced the prevalence of *Bd* (Searle *et al.* 2011; Venesky *et al.* 2014b). Obviously these findings are dependent on species-specific interactions of amphibians and the pathogen; the documented existence of amphibian reservoirs and/or vectors for *Bd* demonstrates that the actual composition of the amphibian community is more important than the simple addition of species.
- Differences in *Bd*'s pathogenicity – at the global scale *Bd* lineages are thought to differ in virulence, reflecting their degree of pathogenicity in the lab (Farrer *et al.* 2011). However, within a given landscape, where we have seen authors raise this possibility as an explanation for why certain populations or individuals are better at coping with the pathogen, they quickly reject it due to the local existence of only one *Bd* lineage (e.g., Doddington *et al.* 2013).
- A combination of subtle environmental variables – Strauss and Smith (2013) put forward this idea to explain the presence or absence of *Bd* in ponds in Missouri, USA, but found little support for it.

Longer-term persistence of *Bd* susceptible populations could be because of any one of the possibilities listed above, *plus*:

- Density dependence – low density of hosts meaning lower transmission such that individuals rarely exceed a threshold *Bd* load that would commonly lead to mortality. We again include the model here as an explanation as to why some populations persist in a post-wave environment (Briggs *et al.* 2010).
- Environmental context of the site (meaning either temperature or moisture) – as mentioned previously, the prevalence of the infection and disease load within host populations has been shown to vary markedly with these variables. There is evidence, for example, that reduced tree cover associated with higher temperatures makes *Bd* less prevalent among amphibians (Van Sluys & Hero 2009), or both reduce prevalence and *Bd* load (Becker & Zamudio 2011; Becker *et*

al. 2012). Also, seasonal variations in temperature and moisture have been shown to correspond to either increased prevalence or *Bd* loads at different times of year (Berger *et al.* 2004; Retallick *et al.* 2004; Longo *et al.* 2010; Kinney *et al.* 2011). This might create a scenario where some individuals of a population persist by surviving until *Bd* loads are low and can reproduce before the seasonal peak of *Bd* arrives. It is also possible that such a dynamic requires only a slight difference in temperature or moisture to turn a site from one that supports a population of amphibians to one that does not. For example, a detailed study of two populations of *Alytes muletensis* has shown that site-level differences, and not density dependence, explain whether or not a population of this species is successful in response to the presence of *Bd* (Doddington *et al.* 2013).

- Decreased virulence of the pathogen over time – this is commonly seen for other pathogens. It could arise because of a decrease in pathogenicity or the development at a population level of an acquired immune response. The acquired immunity option is the same as above, but it would presumably be one that increased within the population as a result of selection over time (and could allow for an increase in the host population). We have not seen the decrease in pathogenicity within a site over time put forward in a serious way. Like the differences of pathogenicity listed above, reduced pathogenicity does not lend itself to our current understanding of *Bd* at the site level. However, we discuss the possibility of changing pathogenicity in other contexts and the reasons why it is an important research topic in another section (page 291).

- Mortality is compensatory instead of additive – this derives from models to manage the exploitation of species (i.e., hunting and fishing). Wildlife and fisheries managers set quotas for the amount of take allowed. For many exploited species there are times of the year when resources (e.g., food, shelter) are limiting and individuals die. The management goal is to harvest the portion of the population that would die naturally (compensatory mortality) before the resource limitation occurs. Harvest in excess of this amount is additive, leading to population reductions. In the context of disease, Tobler *et al.* (2012) have invoked the possibility that amphibian populations could persist even with mortality from chytridiomycosis if the mortality was only compensatory. Because the idea of compensatory mortality relies on a naturally occurring density dependent period, it is similar to the density dependent model, but there is a key difference. When Briggs *et al.* (2010) showed that individuals with repeated infections and low *Bd*

loads in a low density enzootic situation had mortality comparable to disease-free individuals, density dependence was a good explanation. However, Scheele *et al.* (2014) found it difficult to invoke a density dependence model when they encountered a species having high *Bd* loads leading to mortality, whose population size was increasing and its range expanding. Compensatory mortality might make more sense in such cases, yet there still should be limits to population increases. Muths *et al.* (2011) discussed a situation in which increased recruitment in a population of Boreal Toad (*Anaxyrus boreas* NT) compensated for higher mortality due to *Bd*. The cause of the higher recruitment was unknown, but again it could relate to reduced adult density.

Final thoughts on chytridiomycosis:

During the course of our project we walked a number of beautiful montane streams that were devoid of frogs and salamanders. Occasionally we walked several of these streams in the same night, and we would encounter a small number of tadpoles. At one point, we found an adult *Craugastor* sp. in a pool in the Sierra de Juárez that had died from chytridiomycosis, and there were tadpoles of more than one species nearby that probably belonged to highly threatened treefrogs. On two occasions near Totontepec we saw toad tadpoles that might have belonged to *Incilius spiculatus* (EN). As we note in our section on Totontepec (see page 154), we found tadpoles and metamorphs of what was likely *Plectrohyla psarosema* (CR). In each of these instances, and many others that haunt us, the adults were nowhere to be found and who knows how much longer the tadpoles will continue to be produced. Knowing what we now know about density dependence coupled with the susceptibility of the metamorph stage of development, we should have been actively capturing these tadpoles, clearing them of *Bd*, and rearing them into frogs for release from where they came. AfriCam Safari, the world-renowned zoo in Puebla, has shown that this is possible. They started an *ex situ* breeding program for the last known remaining individuals of *Incilius cristatus* (CR) (tadpoles discovered at one site in Puebla) (Santos-Barrera *et al.* 2010; see also http://www.helpafrog.org/toad.htm). AfriCam's experience recovering remnant frog populations should be called upon for future work in southern Mexico.

Box I-2. Climate Change and Chytridiomycosis

Over the past decade, the two most contentious questions within chytridiomycosis research have been whether *Bd* was native or introduced (in general), and whether or not climate change has played a major role in the prevalence/destructiveness of chytridiomycosis. The two questions have at times been closely linked with one hypothesis being that *Bd* has always been present in Central America (and Mexico) and has become destructive due to recent climate change. Over time, this hypothesis has become less compelling to most researchers, and the position usually appears now as a straw man in the literature. Thus, increasingly, there is general acceptance that *Bd*-GPL is not native to the region, but uncovering what role, if any, climate change has played remains controversial.

Researchers have put forward several hypotheses whereby the spread of *Bd* and/or its virulence is enhanced by climate change. Here, in brief, we lay out the hypotheses and some of the key citations for each. Before proceeding, however, we reiterate a couple of points from the main text. It is useful to view chytridiomycosis through the traditional lens of the disease triangle, where virulence is determined by the dynamic interaction among pathogen–host–environment. In this case, there appear to be situations in which *Bd* overwhelms naïve host populations to an extent that environmental change need not be invoked. Indeed, some species held in ideal conditions are completely eliminated by the pathogen. There are, however, situations in nature where the environment is an important factor driving and/or mitigating the disease. *Bd* growth, in particular, is greatly influenced by environmental conditions, especially temperature and moisture.

One of the hypotheses argues that chytridiomycosis is made worse by droughts, which have increased as a result of climate change. During these droughts, amphibians congregate at the remaining water sources, thus increasing contact between individuals and facilitating the spread of disease (Pounds *et al.* 1999). Also, amphibians could be more susceptible to chytridiomycosis if drought causes stress in the animals (Lampo *et al.* 2006). Anchukaitis & Evans (2010) showed that Golden Toad (*Incilius periglenes* EX) declined at a time of extreme drought brought on by the 1986–1987 El Niño and chytridiomycosis; however, the authors note that there is considerable debate as to whether or not global warming has influenced El Niño trends. Li *et al.* (2013) summarized the counter-arguments to the drought-climate-change-enhanced chytridiomycosis hypothesis.

Another possibility has been the chytrid-thermal-optimum hypothesis, whereby increased temperature (brought on by global warming—particularly at night with raised cloud levels) has made montane conditions ideal for *Bd* growth. This hypothesis was put forward most famously by Pounds *et al.* (2006), and it has fallen out of favor in recent years. The hypothesis relied heavily on a dataset of disappearance of *Atelopus* frogs throughout Central America (La Marca *et al.* 2005) in relation to climate variables. Rohr *et al.* (2008) reanalyzed these data and concluded that the associations between frog disappearances and temperature increases

were not as strong as many other variables that one could postulate. Furthermore, Rohr *et al.* (2008) argued that the correlation that did exist was actually in the reverse direction, thus showing a worse environment for *Bd* growth with climate change. Lips *et al.* (2008) also rejected the findings of Pounds *et al.* (2006) on several grounds. Most pertinent to the current discussion, however, was Lips *et al.*'s (2008) argument that the *Atelopus* data were ill-suited for making large-scale correlations between frog declines and climate data. Specifically, Lips *et al.* (2008) contended that the error introduced, when one accounts for the difference between Last Year Observed records for frogs versus their actual Date of Decline (which was not measured), makes the *Atelopus* data unable to say anything meaningful about possible relationships with other temporal data.

Several authors have put forward the idea that climate variability brought on by climate change has increased the prevalence of chytridiomycosis. Using the *Atelopus* data, Rohr and Raffel (2010) showed that temperature changes related to El Niño events (as opposed to simple temperature means) coupled with *Bd*, modeled as an invasive pathogen, helped explain the spread of the disease. More recently, the same authors from Rohr and Raffel (2010) have again reanalyzed the *Atelopus* data to show that declines are associated with variability as measured by month to month decreases in temperature (Raffel *et al.* 2013).

In a series of controlled experiments, Raffel *et al.* (2013) also demonstrated that a frog species normally tolerant of *Bd* would develop infections when temperatures dropped suddenly. Temperature drops alone, however, were not enough to affect the survival of Cuban Treefrog (*Osteopilus septentrionalis* LC); the drop in temperature also had to be random. The authors suggested that *Bd*, being a fast reproducer, would be quicker to recover from sudden drops in temperature relative to the immune systems of the frogs. But Raffel *et al.* (2013) showed that a regular pattern of temperature change, such as differences between night and day, would not interrupt the immune system of the host. The final piece of Raffel *et al.*'s (2013) argument is that because climate change leads to increases in climate variability and increased temperatures overall, there is both a heightened likelihood of sudden temperature changes and farther to fall in terms of temperature.

Raffel *et al.* (2013) weaved multiple lines of evidence together to form a whole. We treat their work seriously because it encapsulates the most credible scenario for linking amphibian declines to climate change for our region. It also would appear to explain other observations and findings. Woodhams *et al.* (2008), for example, showed that sudden drops in temperature causes *Bd* zoosporangia to release zoospores, and Ribas *et al.* (2009) showed that the host's innate immune response was less effective at reduced temperatures. Cold temperatures tied to changes in season have occurred along with increases in *Bd* loads (Retallick *et al.* 2004; Kinney *et al.* 2011). Also, cold snaps have been observed by multiple researchers as contributing to the severity of outbreaks—here are a few examples. Berger *et al.* (2004) noted sudden drops in temperature have been witnessed in relation to Australian amphibian

deaths, and the authors drew an analogy to a fish disease in which sudden cold does not allow the immune system of the host to keep pace with its pathogen. Whitfield *et al.* (2012:782) tracked *Bd* prevalence for a year, locating relatively few dead frogs in the process; however, those "dead or moribund frogs that have been found have only [been] found in cooler months and are found particularly frequently during periodic mid-winter cold fronts (S. M. Whitfield, pers. obs.)". Norman Scott (1993) observed something similar in what is regarded as the first account of chytridiomycosis. Scott (1993) described the wave-like spread of the disease to new areas as occurring at differing spatial scales in considerable detail for a short piece. He then went on to state that "the dead and moribund animals are usually encountered during or immediately after brumation, or unusually cold periods" (Scott 1993:1). Of course, this example, like the others before, is highly anecdotal, but it is telling that on every other point Scott made in his piece he has proven remarkably accurate.

The arguments against the conclusions of Raffel *et al.* (2013) are relatively straightforward. First, the connection to broad-scale climate data is tenuous at best. There are those who maintain that while the *Atelopus* data might show strong correlations with a climate dataset, the data themselves are still inappropriate for that purpose (a repeat of the argument from Lips *et al.* 2008). The climate data are also notoriously coarse (with changes from month to month serving as a proxy for sudden cold snaps). Furthermore, a global examination of monthly temperature data for sites alongside the odds of *Bd* detection found that temperature variability decreased the chances of the pathogen's presence being detected (Olson *et al.* 2013). Second, Raffel *et al.*'s (2013) lab studies on Cuban Treefrogs do not represent the natural world. Thus, the sudden drops in temperature have been criticized as being unrealistically extreme (Terrel *et al.* 2013). Another issue is that the compromised immune system of the host was surmised, but no portion of the immune system was actually reported by Raffel *et al.* (2013). As a consequence, the lab results did not give any indication of the mechanism behind the purported differential acclimatization between host and pathogen (Terrel *et al.* 2013). This is problematic because the main reason to conduct lab experiments is to gain a mechanistic understanding.

The debate over climate change's influence on the spread of chytridiomycosis is unlikely to disappear any time soon. Even if sudden temperature drops prove to be the key piece of the environment portion of the disease triangle, the link to climate change is not decisive. It is also difficult to get any sense of the counterfactual. In other words, suppose climate change has aided the spread of chytridiomycosis through Mexico and Central America, what would this spread have been like without climate change? Would the spread have been noticeably less rapid or severe? This last question is perhaps the most important one and it is extremely difficult to answer definitively.

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II: SITE PROFILES

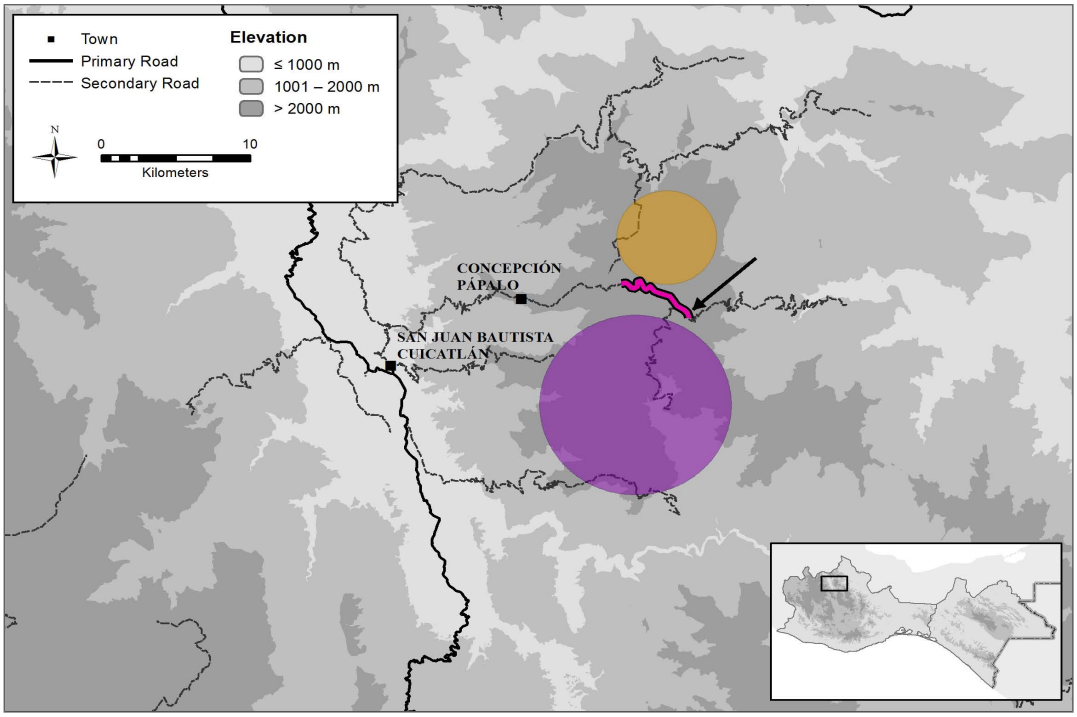
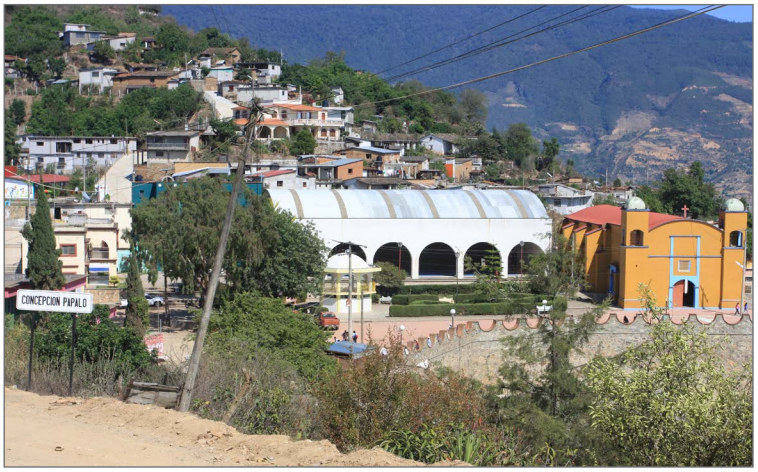


Fig. II-1. Map of the Concepción Pápalo AZE site. The purple polygon represents the range of *Thorius papaloae* according to the IUCN Red List (Parra-Olea *et al.* 2008); specimens discussed by Hanken and Wake (2001) originated from along the pink line. Also shown is the IUCN Red List range of *Pseudoeurycea aurantia* (orange polygon; Canseco-Márquez *et al.* 2008). The black arrow indicates where we located both species.

Concepción Pápalo



Trigger Species	Last Year Observed
Salamander	
Thorius papaloae, EN B1ab(iii)	2009

Located: *T. papaloae* – 3 individuals.
Visit: 27–29 May 2009.
Conservation contacts: We do not know of any NGO working at the site. Government entities include: CONAFOR and CDI.

Delineation

Throughout the course of our project we thought *T. papaloae* was restricted to a small patch of montane forest above the town of Concepción Pápalo. Only in the late stages of review did we learn of other nearby records of the trigger species. Additional localities for the species include San Juan Tepeuxila, on the road to Santa María Pápalo, and Loma El Viento, San Isidro Buenos Aires. However, because we have no additional information about these other localities our site description remains focused on Concepción Pápalo. An argument could be made that the expanded site is too large for a single species AZE site. We retain it here because we believe that the other localities are very likely to be at the periphery of the species' range. Moreover, the localities are part of a single biogeographical unit that is now disjunct due to humans.

Background

The Concepción Pápalo AZE site is triggered by *T. papaloae*. The site is named for the town of Concepción Pápalo, Oaxaca, where most of the records of the salamander originate. The word "papalo" means "place of butterflies" in Cuicateca, the indigenous language spoken here. The easiest way to reach the town by car is on the road from San Juan Bautista Cuicatlán. This takes about one hour, but will soon be a quicker trip because the road between the two towns is being paved. At the time of our visit, all but the last six kilometers were paved. Roadwork was being held up

by funding disputes and the townspeople did not know when it would resume.

The town sits at 2048 m. Binford (1989) did not list Concepción Pápalo in his gazetteer of bird collection sites, but he mapped the area as being dry pine–oak at lower elevations and humid pine–oak at higher elevations. Below the town oaks dominate. Mixed pine and oak forests occur within the town, with pine trees becoming more dominant at higher elevations. The highest elevations, however, no longer contain forest due to recent fires. Driving east of town, one comes to a split in the road at about 13.5 km. The split is at high elevation where much of the forest has been lost. To the right the road continues to the town of Santa María Pápalo and to the left it heads towards Peña Verde. As the road to Peña Verde descends in elevation, forest returns on the north side of the mountain. The forest here is noticeably moister and becomes increasingly dominated by broadleaf trees.

According to INEGI, the municipality of Concepción Pápalo has a population of 3,077 people. The municipality is inhabited by an indigenous group called Cuicateco. About half of the people speak Cuicateca, but it is starting to disappear (both from the town and in general). Most of the older inhabitants are fluent; however, few of the young people speak it and school classes are conducted in Spanish. Don Germán Martínez, president of the commissariat of the town, says that the overall population has also been declining because people are migrating to Mexico City and the United States to find better jobs. This depopulation is evident from the reduction in the town's school, which used to have five teachers and six classrooms, but now only has two teachers and three classrooms.

The main livelihood in the municipality is agriculture. The *Encyclopedia of Mexican Municipalities* (INAFED 2010) lists the primary crops as corn and beans. According to the commissariat, however, the municipality produces mainly cold-climate species such as nuts and quince, as well as some avocados and bananas. The greater municipality and the town have a sufficient water supply for domestic use and for agriculture, although the topography of the region makes irrigation difficult.

Conservation measures

According to the town commissariat, there are currently 13,340 forested hectares; 2,300 ha are in a conservation zone and 7,500 ha are classed as "forest zone." The town is in charge of managing the forests within the municipality. Until two years ago, there was no conservation management plan, but such a plan is now in place. The primary reason for conservation is to ensure the water supply, but also to preserve resources for the children of the municipality. The management regime is strict such that none of the timber harvested is sold outside of the municipality. An exception to this rule occurred in 2008 when the commissariat allowed a sale of five hectares of timber to Oaxaca City. This sale was part of a CONAFOR-aided

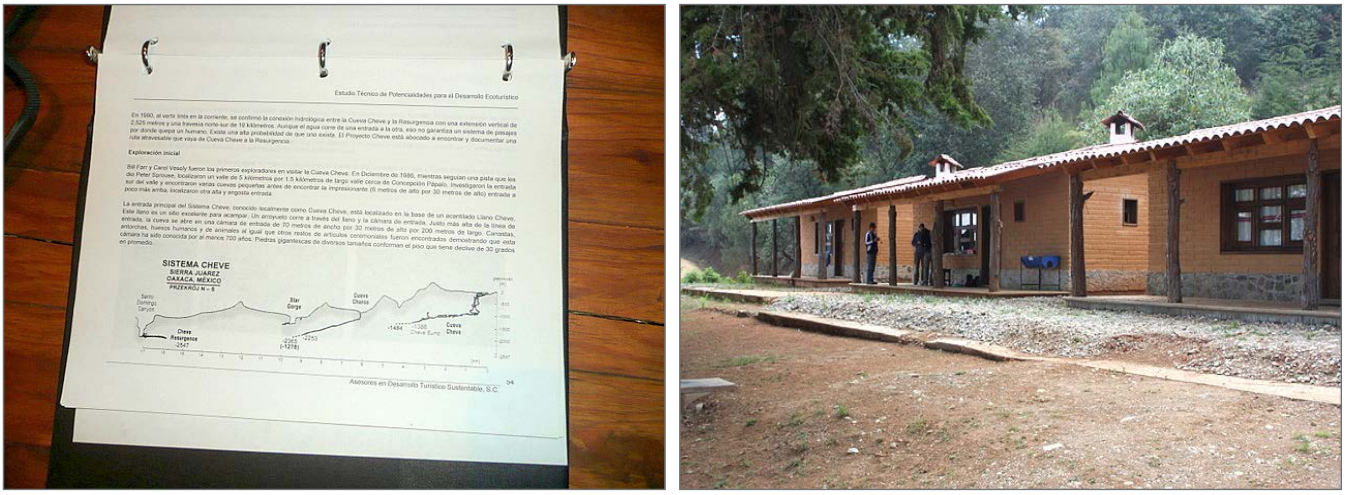


Fig. II-2. Map of the deep caves in the municipality of Concepción Pápalo (left). New tourist cabins that the town constructed for visiting cavers. The town generously allowed us to stay in them prior to their official opening (right).

recovery plan to extract salvage timber that had been destroyed by a bark beetle infestation. Under normal circumstances, one must submit a written request to the president of the commissariat explaining the need for a given quantity of wood before any tree is cut. Hunting or harvesting of any non-tree species from the forest zone is forbidden. CONAFOR has also helped the town develop a plan for ecosystem services. They are two years into a five-year plan.

The municipality has an ecotourism plan to expand infrastructure supported by CONAFOR, along with CDI. They are two years into this project, which includes the construction of cabins for visitors (Figure II-2). At this time, there are no specific plans about where the revenue generated from the cabins will go, but the funds are slated to benefit the needs of the townspeople. The town expects ecotourism to generate employment opportunities. The principal tourist attraction is Chevé Cave (*Sistema Chevé*), which has been visited by people from around Mexico, Europe, and the United States (Figure II-2). It is famous among cavers because it is considered the second deepest cave in North America and is listed as the twelfth deepest cave in the world.[1] The current confirmed depth is 1484 m; however, some experts believe Chevé Cave has the potential to be the deepest cave in the world.[2]

In addition to ecotourism, an impetus for conservation in the municipality came as a result of a huge fire that destroyed more than 370 ha of forest in May 1998

[1] The most recent peer-reviewed lists of which we are aware have been authored by Bob Gulden, putting Chevé Cave as the world's tenth (1996) and ninth (2004) deepest. The website list of deepest caves by Gulden, however, appears to be the most up to date and well documented, which has Chevé Cave as the twelfth deepest (Gulden 2014).

[2] For example, see article by Philipps (2006). Matt Covington also has an interesting discussion on his website. Viewed 26 May 2014, and available at: <http://www.speleophysics.com/mdcovin/play/cheve.html>

Fig. II-3. Top left: the mountain of Concepción Pápalo. Notice agriculture moving upslope and at the peak a lighter color where forest was eliminated by fire. Top right: Agriculture on the slopes of Concepción Pápalo. Bottom panels: two views of the top of Concepción Pápalo. This area was forested until a massive fire in 1998.

(Figure II-3). Prior to this fire (since "time immemorial"), the mountain tops near town were covered by tall trees that often exceeded two meters in diameter. The fire was extremely large according to the townspeople because the understory had been building up before the fire. Nineteen ninety-eight was an extremely bad year for forest fires throughout our region and Mexico in general (see "Fire" on page 18). Fire of course rises, so it is no surprise that the summits within the municipality were most affected. The 1998 fire was extremely hot, burning not only the tallest trees and ground surface, but also the soil beneath the surface. Replanting of forest is not typically practiced in the municipality, but for three years following the fire (1998–2000) the people conducted reforestation projects. Each year since the 1998 fire there have been smaller fires, and these are thought to be due to natural causes. Bark beetle infestations now occur annually, and were particularly devastating in 2008, though they were unknown here prior to the 1998 fire.

Most of our information about Concepción Pápalo comes from interviewing the

Fig. II-4. Meeting with the town commissariat.

town leaders just prior to searching for *T. papaloae* (Figure II-4). Perhaps the most immediate conservation action for anyone interested in the salamander would be to show the locality (the small part currently confirmed to have *T. papaloae*) to town leaders and establish that it is within the conservation zone. If our discussions with locals are indicative of anything, it is that they appreciate their unique species (see Figure II-5). If it is not within the conservation zone, all efforts should be directed towards securing the forest patch. There are many other conservation priorities and opportunities in Concepción Pápalo, but this would be a logical starting point.

Species Accounts

Thorius papaloae, EN B1ab(iii)

Thorius papaloae is known from forests near the town of Concepción Pápalo in the mountains of north central Oaxaca. Although the first specimen was collected by E. W. Nelson and E. A. Goldman in 1894 (USNM 047797), more than a century would pass before the species was described (Hanken & Wake 2001). Canseco Márquez and Gutiérrez Mayén (2010) list the elevational range of species as being from 2090–2850 m and also include nearby localities: San Juan Tepeuxila, the road to Santa María Pápalo, and San Isidro Buenos Aires. One specimen from "Loma El Viento, San Isidro Buenos Aires" (17° 56.086' N, 96° 52.262' W) was collected by Gabriela Parra Olea, David Wake, and Mario García-París on 15 January 2002 (S. Rovito, pers. comm.). The most recent record of the species of which we are aware is that of Sean Rovito who photographed *T. papaloae* "between Concepción Pápalo and Peña Verde" 19 December 2009 (Rovito 2009)—following our visit.

We found three individuals of *T. papaloae* while driving out of Concepción Pápalo towards Peña Verde on the left-hand side of the road just after the split to Santa María Pápalo, 28–29 May 2009 (Figure II-6). It was from within this same forest patch that Rovito (2009) found *T. papaloae*, though he was about 500 m apart from us. Locals said the patch of forest is just within the boundary of the Concepción Pápalo municipality. We found each of the three *T. papaloae* individuals under small logs on the forest floor. The three logs were similar in shape and size (resembling firewood) and were less than five meters from each other. We looked for *T. papaloae* at all of the collection localities (stopping points on one road NE of the town of

Fig. II-5. Recording information about the amphibians found at Concepción Pápalo (top left). Vials with swabs from amphibians at Concepción Pápalo to test for *Bd* (top right). RCH shows off a salamander to folks eager to take their picture (bottom left). RCH swabbing a salamander at Concepción Pápalo (bottom right).

Concepción Pápalo) discussed by Hanken and Wake (2001), but we failed to find the species. We also searched additional forests on the road to Santa María Pápalo without success.

The Red List category and criteria for *T. papaloae*, EN B1ab(iii), seem appropriate to us. Hanken and Wake (2001) discussed Concepción Pápalo as it was prior to 1998. The AZE site is now a very different place as a result of the 1998 fire, which destroyed much of the high-elevation forest. The Red List account for *T. papaloae* (Parra-Olea *et al.* 2008) should emphasize this threat in the text. Right now the greatest threats to *T. papaloae* are fire at the high elevations and deforestation/cultivation moving up the mountain sides. Together these threats leave a narrow band of forest habitat for the species. The municipality is making efforts to control logging and manage its resources, and perhaps this will keep the remaining forest intact. However, it is too soon to conclude that deforestation and cultivation no longer constitute a major threat, and small localities, such as the forest where we found

Fig. II-6. *Thorius papaloae* at Concepción Pápalo.

T. papaloae, need long-term protection. Presumably the other localities where this species occurs face similar challenges, and a key research priority should be to learn more about their conservation situation.

Notes on other species of interest

Pseudoeurycea aurantia, VU A3c; B2ab(i,ii,iii)

Canseco-Márquez and Parra-Olea (2003) described *P. aurantia* from 10 specimens collected at a single locality, 7 May 2000 (17° 50.20' N, 96° 47.05' W). Sean Rovito photographed the species 13 and 15 August 2008 from "East of Concepción Pápalo," which could be the type locality (Rovito 2008). We found 15 individuals of *P. aurantia* at the same locality as *T. papaloae* (see above) on 28–29 May 2009 (Figure II-7). These three sets of records are the only ones of which we are aware for *P. aurantia* and they are likely to be very close to each other. Thus, we agree with the Red List account statement, "the species is currently only known from one locality" (Canseco-Márquez *et al.* 2008). However, we view the Red List account's depiction of the species' range as "likely to have a maximum EOO of less than 20,000 km^2" to be overly optimistic.

Fig. II-7. *Pseudoeurycea aurantia* at Concepción Pápalo (top panels). Locality above Concepción Pápalo (at ca. 2800 m on the road to Peña Verde) where we found *Thorius papaloae*, *Pseudoeurycea aurantia*, and *Mesaspis juarezi* (bottom panels).

Thorius papaloae has been found over the years at several localities east of Concepción Pápalo. It has sometimes been found in association with a *Pseudoeurycea* species that resembles *Pseudoeurycea smithi* (Hanken & Wake 2001). This mystery *Pseudoeurycea*, however, appears to be *Pseudoeurycea papenfussi* (NT) (Parra-Olea *et al.* 2005), which would mean that *P. aurantia* has not been located at the other *T. papaloae* localities. Perhaps the distribution of the species will be proven to extend farther, but this is not guaranteed.

Currently, the Red List map for *P. aurantia* covers 33.84 km^2 (Canseco-Márquez *et al.* 2008), or 27% of the EOO given for *T. papaloae*. If *P. aurantia* were known from pristine habitat that extended beyond the collecting locality perhaps the assumed EOO would make sense, but this forest is highly fragmented. Furthermore, the Red List polygon fails to encompass the only known locality for the species (Figure II-1, page 90).

The threats listed in the Red List account for *P. aurantia* should match those of *T. papaloae* because they are known from the same area. The most immediate threat to both species is the possibility of deforestation of the locality where the two are known to exist. As stated above, we believe the people of Concepción Pápalo would be amenable to protecting the parcel of trees were they to be informed of its importance. Over the long term, the threat of small-scale deforestation for agriculture moving up the mountain is a major threat, as is fire.

In our opinion, *P. aurantia* should be uplisted using the current B criterion and a smaller EOO. The Red List's own map polygon would qualify the species as CR (the cutoff under B is 100 km^2 for CR, see Appendix 3). At the very least this species warrants an EN listing. We have no reason to doubt the A criterion listed for *P. aurantia*, although it would become moot by uplisting under B. Should our position of uplisting be adopted by IUCN, *P. aurantia* would serve as an additional trigger for the Concepción Pápalo AZE site.

Mesaspis juarezi, EN B1ab(ii)

Mesaspis juarezi occurs in both Concepción Pápalo and Sierra de Juárez, yet the information in the current Red List account would qualify it as an AZE species. The Red List account (Canseco-Márquez 2007) classifies *M. juarezi* as EN and considers it confined to the Sierra de Juárez AZE site (page 105) where it could serve as an additional trigger species. The lizard was not included on AZE (2010) because it belongs to a taxonomic group of reptiles that has not been globally assessed by IUCN (a necessary stipulation in order to make comparisons among AZE sites, but one that has no bearing on the species in terms of conservation). Thus, a species can serve as an AZE trigger species, but it will not appear on the global list until its group is entirely assessed. However, it is now clear that *M. juarezi* also occurs in Concepción Pápalo, which means it no longer qualifies as an AZE trigger species.

All museum records from which the species was described (see Karges & Wright 1987), as well as all additional records that we found in online databases (MVZ 191050; LSU 38439–40, 38442–43, 38465–69; IBUNAM AR8537; CAS 142597) come from the Sierra de Juárez. The most recent of these museum records is from 1990 (IBUNAM AR8537). We found *M. juarezi* at ca. 2800 m on the road to Peña Verde (Figure II-8). Gutiérrez Mayén (2001) reported the species from close to Concepción Pápalo at Peña Verde (2805 m)—possibly at the same location where we found it. Canseco Márquez and Gutiérrez Mayén (2010) map the species at two locations on the same massif as Concepción Pápalo and they list 10 records (EBUAP 1780–84) and (MZFC 8693–97), none of which are available online[3] via HerpNET or REMIB (MZFC is a partner to both online collaborations). We are aware of

[3] As of 26 May 2014.

Fig. II-8. *Mesaspis juarezi* from Concepción Pápalo on the road to Peña Verde.

only two other herptiles that are known from just Concepción Pápalo and Sierra de Juárez, *Pseudoeurycea papenfussi* and *Chiropterotriton* sp. J.[4]

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[4] The latter species has never been formerly described. Darda (1994) first discussed it as yet another species from the Sierra de Juárez, but it has also been found near Peña Verde (S. Rovito, pers. comm.).

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Table II-1. Amphibians encountered at Concepción Pápalo, 27–29 May 2009. AZE species are marked with an asterisk (*).

Species	Date	Lat/Long	Elev
Pseudoeurycea aurantia	28 May 2009	N17 49.931 W96 46.816	2786 m
Pseudoeurycea aurantia	28 May 2009	N17 49.901 W96 46.806	2790 m
Pseudoeurycea aurantia	28 May 2009	N17 49.901 W96 46.806	2790 m
Pseudoeurycea aurantia	28 May 2009	N17 49.930 W96 46.826	2779 m
Pseudoeurycea aurantia	29 May 2009	N17 49.889 W96 46.803	2788 m
Pseudoeurycea aurantia	29 May 2009	N17 49.884 W96 46.773	2783 m
Pseudoeurycea aurantia	29 May 2009	N17 49.884 W96 46.773	2787 m
Pseudoeurycea aurantia	29 May 2009	N17 49.884 W96 46.773	2787 m
Pseudoeurycea aurantia	29 May 2009	N17 49.884 W96 46.773	2787 m
Pseudoeurycea aurantia	29 May 2009	N17 49.884 W96 46.773	2787 m
Pseudoeurycea aurantia	29 May 2009	N17 49.884 W96 46.766	2792 m
Pseudoeurycea aurantia	29 May 2009	N17 49.884 W96 46.766	2792 m
Pseudoeurycea aurantia	29 May 2009	N17 49.884 W96 46.766	2792 m
Pseudoeurycea aurantia	29 May 2009	N17 49.884 W96 46.766	2792 m
*Thorius papaloae**	29 May 2009	N17 49.884 W96 46.773	2783 m
*Thorius papaloae**	29 May 2009	N17 49.884 W96 46.773	2787 m
*Thorius papaloae**	29 May 2009	N17 49.884 W96 46.773	2787 m

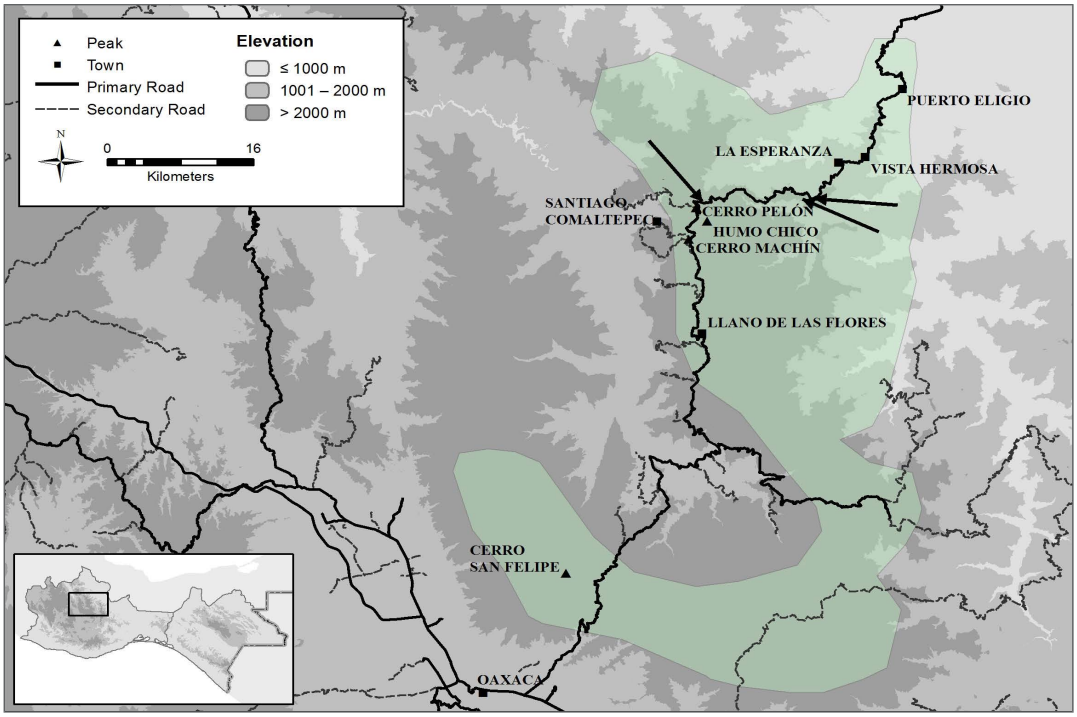

Fig. II-9. Map of the Sierra de Juárez AZE site. The green polygon represents the extent of the site. Two black arrows indicate where we located AZE trigger species (from left to right: *Thorius aureus* and *Pseudoeurycea saltator*).

Sierra de Juárez

Trigger Species	Last Year Observed
Frogs	
Craugastor polymniae, CR (PE) A2ace	2009
Duellmanohyla ignicolor, EN B1ab(iii)+2ab(iii)	1994×
Ecnomiohyla echinata, CR (PE) A2ace	1969
Megastomatohyla mixe, CR B1ab(iii)+2ab(iii)	1993
Plectrohyla calvicollina, CR (PE) B1ab(iii,v)+2ab(iii,v)	1980
Plectrohyla celata, CR (PE) B2ab(iii,v)	1981
Plectrohyla cyanomma, CR (PE) B1ab(iii,v)+2ab(iii,v)	1980
Plectrohyla hazelae, CR (PE) A2ace	2004
Plectrohyla sabrina, CR A3ce	2000
Salamanders	
Pseudoeurycea orchileucos, EN B1ab(iii)	2000•
Pseudoeurycea saltator, CR B1ab(iii)	recent
Pseudoeurycea smithi, CR A2ace	1999□
Pseudoeurycea unguidentis, CR B1ab(iii,v)	1976*
Thorius adelos, EN B1ab(iii)	1976
Thorius arboreus, EN B1ab(iii)	2010
Thorius aureus, CR B1ab(iii,v)	2010
Thorius boreas, EN B1ab(iii,v)	2009
Thorius pulmonaris, EN B1ab(iii,v)	1997‡
Thorius smithi, CR B1ab(iii)	2010

× Lips *et al.* (2004) reported finding 13 tadpoles in 2000 that they tentatively assigned to *D. ignicolor*.

• Possibly as recently as 2009 by S. Rovito (see species account below).

□ According to the Red List account (Parra-Olea & Wake 2008).

*** According to the most recent records on HerpNET (2014) (MVZ 138508–16; USNM 204932–33) and the Red List account of specimens from the type locality—other records exist from elsewhere within the Sierra de Juárez, but their identity is uncertain and we have no date for them (Parra-Olea *et al.* 2008a).**

‡ The most recent record is from 7 October 1997 from 5 km S of La Cumbre along

Highway 175 (MCZ A-148742) (Parra-Olea *et al.* 1999; and J. Hanken and S. Rovito, pers. comm.).

Located: We located none of the AZE frogs listed for this site. Of the salamanders, we found: *P. saltator* – 2 individuals, *T. aureus* – 3 individuals.
Visits: 4–7 September 2008, 10–12 November 2008, 24–26 June 2009.
Conservation Contacts: There are numerous conservation contacts for the site, each with differing interests and focus. NGOs include: ERA, FSC, and WWF–México. Government entities include: CDI, CONAFOR, PROFEPA, and SEMARNAT.

Non-amphibian AZE Triggers (not covered in this site account)

Mammals[1]
Habromys chinanteco, CR B1ab(iii)
Habromys ixtlani, CR B1ab(iii)
Megadontomys cryophilus, EN B1ab(iii)[2]
Microtus oaxacensis, EN B1ab(iii)

Delineation

The mountains of northern Oaxaca, and this site in particular, represent the most difficult region in Mexico to delineate in terms of AZE (see Box IV-1, page 241, for an expanded discussion). The 2005 AZE list included five sites within the Sierra de Juárez: "Cerro Pelon I," "Cerro Pelon II," "Cerro Pelon III," "Sierra Norte," and "Northern slopes of the Sierra de Juarez." At the beginning of our project, we felt that these five sites should be combined into a single site on the basis of manageability. The previous five-site treatment also did not make sense biologically. For example, *Plectrohyla calvicollina*, the trigger for the "Cerro Pelon II" site, has only been found twice. On one of these occasions it was sitting on the same rock as *Plectrohyla celata*, the trigger for "Cerro Pelon III," so the creation of two separate sites for these species was inappropriate.

There is a large elevational gradient from one end of the Sierra de Juárez to the other and the AZE species occur at different elevations. The species, however, do not uniformly fit into vegetation zones, but rather overlap one another in distribution such that drawing hard lines between, say, the upper cloud forest species and the pine–oak forest species would be problematic.

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[1] It is worth noting that all four mammal species are likely still present within the AZE site. In surveys, from July 2005–October 2006, Briones-Salas *et al.* (2012) found each of these on Cerro Pelón. Finding *H. chinanteco* was particularly important, because it was the first time the animal had been located in 33 years despite numerous attempts by researchers (Briones-Salas *et al.* 2012).

[2] This species probably does not qualify as an AZE trigger species. See page 249 for a discussion of it.

There are strong arguments to be made that in addition to the five original sites more area should be added. We think that Cerro San Felipe should be included because of biological affinities with the rest of the Sierra de Juárez and because of its accessibility (i.e., lying along Highway 175 outside of Oaxaca City). However, we know little about Cerro San Felipe and we would not be surprised if it were considered a separate AZE site in the future.

For the present, we include three species from Cerro San Felipe in a greater Sierra de Juárez that could trigger a separate site based on current information: *Plectrohyla hazelae*, *Pseudoeurycea unguidentis,* and *Thorius pulmonaris*. Each of these has taxonomic issues. The Red List account for *P. hazelae* followed Duellman (2001) in mapping the species in the Sierra de Juárez as well as near Cuquila, Oaxaca and in the Sierra Madre del Sur of Guerrero (Santos-Barrera & Canseco-Márquez 2004a). Mendelson and Kabay (2009) discounted the non-Sierra de Juárez records on a number of grounds. They also cast doubt about a record (KUH 137037) from between Tlahuitoltepec and Tamazulapan—both in terms of its identity (it is a "barely post-metamorphic individual" that is hard to identify to species) and its location (it could be a misspelling of a town near Cuquila or in what would be the Totontepec AZE site). Mendelson and Kabay (2009) map KUH 137037 with a question mark in the Totontepec AZE site. Given that the only known records are from the Cerro San Felipe portion of Sierra de Juárez AZE site, the species qualifies as an AZE trigger. *P. hazelae* was a 'lost' species which had been last seen in 1975, and Mendelson and Kabay (2009) concluded that it probably went extinct not long after that time. However, the species was rediscovered at two localities within the Sierra de Juárez AZE site early this century: 1) from a streambed near El Punto on the eastern slope of Cerro San Felipe (in 2003), and 2) from a small creek near Ixtlán de Juárez (in 2004) (Heimes & Aguilar 2011).

The Red List accounts for both *P. unguidentis* and *T. pulmonaris* include taxonomic notes. *Pseudoeurycea unguidentis* is said to be "known only with certainty from the type locality. Similar looking individuals have been recorded at nearby locations, but the identity of these is uncertain" (Parra-Olea *et al.* 2008a). We are not sure whether or not these "nearby" locations would still be within the Sierra de Juárez site. If the salamanders at those locations prove to be *P. unguidentis* and lie outside the existing boundaries, then the *P. unguidentis* would no longer be considered an AZE trigger species. The situation with *T. pulmonaris* is similar to *P. unguidentis*. The Red List states that "populations attributed [to *T. pulmonaris*] from locations other than the type locality (Cerro San Felipe) need to be confirmed and are currently not included" in the account (Parra-Olea *et al.* 2008b). Some these populations (e.g., from Sierra de Cuatro Venados), if proven to be *T. pulmonaris*, would disqualify it from being an AZE trigger species. We include *P. hazelae*, *P. unguidentis,* and *T. pulmonaris* for the time being, yet because we know so little

about Cerro San Felipe and these species we do not discuss them further.

The Sierra de Juárez contains numerous AZE trigger species that were discovered for the most part in close proximity to Highway 175. The highway runs from Oaxaca City northeast to Tuxtepec (Oaxaca's first and second largest city, respectively). Highway 175 was constructed in the late 1950s. William Duellman first traveled along it in 1959, and numerous other herpetologists soon followed (Campbell & Duellman 2000). The portion of road we discuss here, from Llano de las Flores and Cerro Machín in the south to Puerto Eligio in the north, is highest in the south near Llano de las Flores and the peaks of Cerro Pelón and Cerro Humo Chico (upwards of 3000 m) and loses altitude as it heads north, falling to about 700 m at the edge of the portion covered here. Most of this area, and most of the AZE amphibians, live along the northern slope of this mountain range where rains come in from the Caribbean having passed over the lowlands of Veracruz to the north. Although the bulk of herpetological work in the region has taken place near the highway, we map the AZE site as a larger polygon than the road corridor because it would be feasible to manage as a somewhat larger entity and it would have more biological relevance.

Most of the northern portion of the site falls within a single municipality, Santiago Comaltepec. Another municipality, San Pedro Yolox, is also in the north and a small portion of it runs along Highway 175. The town of San Pedro Yolox is recorded in codices and has been in existence since at least the 1500s. Its people speak the same language as Santiago Comaltepec, and its portion of the Sierra de Juárez site encompasses some important collecting localities including the type locality for *Thorius adelos* and the most recent sighting of *T. smithi*. Sean Rovito (pers. comm.) has said that the people of San Pedro Yolox have always been welcoming and are concerned about conserving their species. In the course of our project, we had little interaction with the San Pedro Yolox community. For this reason we largely confine our discussion of management to the municipality of Santiago Comaltepec.

Our choice of the name Sierra de Juárez from the many options available is based on several considerations. First, any name with just Cerro Pelón or Comaltepec would be overly restrictive and unable to encompass the range of AZE species present. Sierra Norte would be an obvious choice and indeed it is frequently used as a synonym for the area. As a term, Sierra Norte invites confusion because it is the name of the Oaxacan economic zone that includes both the mountains delineated here and the Sierra Mixe to the east (see figure 2, pg.23 in García-Mendoza *et al.* 2004). Briones-Salas *et al.* (2006) considered Sierra Norte to be a local name for the site we delineate, but they preferred to call it the Sierra Madre de Oaxaca. However, relatively few people writing of the area use the term Sierra Madre de Oaxaca and it invites confusion with the well known Sierra Madre del Sur, which

is largely in Oaxaca. The Sierra de Juárez name has the drawback that it often includes Concepción Pápalo (and sometimes the Sierra Mazateca), which we treat as a separate AZE site (see page 91).

Background

The Sierra de Juárez is recognized as being exceptional in terms of its high degree of reptile and amphibian endemism (Hanken & Wake 1994; Casas-Andreu *et al.* 1996, 2004; Campbell 1999). However, this site is extremely important for most major types of Mexican flora (Acosta 2002; García-Mendoza 2004) and fauna (González Pérez *et al.* 2004). We restrict this site account to amphibians that qualify as AZE triggers, but this site also contains a number of non-amphibian triggers.

For many years the higher reaches along Highway 175 were sparsely populated and remained forested, but this was not to last. In his classic *Mammals of Oaxaca*, Goodwin (1969:14) said much of montane Oaxaca was intact because "some high altitudes are too cold and wet for native corn production, and here the cloud forest may remain nearly primeval. A good example of the latter may be seen along the Oaxaca-Tuxtepec Highway, north of the Sierra de Juárez, between 7000 and 9000 feet in altitude." Twenty years later Campbell *et al.* (1989) echoed this sentiment, but noted the change that was taking place in the 1980s:

> "the vegetation covering the northern slopes of the Sierra Juárez in Oaxaca comprises one of the most extensive tracts of cloud forest remaining in México … Previously, owing to the cold, wet environment and poor soils, the portion of the forest between about 1500 and 3000 m was almost uninhabited by humans. However, with the recent advent of hardwood logging, the entire forest is in danger of soon being irreversibly damaged with an associated loss of many species of animals." (pg.491)

As we discuss below, most of the timber logged at the time was destined for a single paper mill.

The best description of the habitats and zonation of vegetation with elevation along this road is often said to be Bogert (1968) and/or Wake *et al.* (1992) (see, for example, Caldwell 1974a; Toal & Mendelson 1995; Mendelson 1997). Neither of these works, however, is focused on vegetation and both leave much to be desired in terms of discussing actual forest types with elevation. Wake *et al.* (1992) contains an excellent cross sectional figure of forest types with elevation to broadly show the major habitats of salamanders along the route.[3] Bogert (1968:14) contains a

[3] In this regard, figure 6 of Wake *et al.* (1992) is similar to figures depicting the Sierra de Juárez in other classic works by David Wake (e.g., Wake 1987; Hanken & Wake 1994).

paragraph concerning the vegetation of the region, the relevant portion of which is:

> "On the summits of the highest peaks and ridges the forest is largely *Pinus hartwegi*, but on the steep slopes below the summits there are a few firs, *Abies religiosa*, and pines of several species, including *Pinus ayacahuite*. Much of the forest around the summits is pine-oak woodland, but at lower elevations, beginning at approximately the 2500-meter contour, such trees as *Liquidambar styraciflua* are encountered. Below this level oaks become progressively less abundant, and the forest near the type locality of the boa is comprised largely of other hardwoods. Tree ferns occur sporadically, but they are more abundant near the 2000-meter contour."

For a current discussion of conifers and oaks found along this track see Del Castillo *et al.* (2004) and Valencia Ávalos and Nixon (2004), respectively.

Certainly the elevational bands along the northern slope differ from the leeward (south facing) side. The highest elevations on Cerro Pelón are brushy and devoid of trees. This is probably not just the result of recent fire, as indicated by the very name of the mountain, which in Spanish translates as "bald mountain." In winter it can be exceptionally cold here. Caldwell (1974a) mentions an ice storm that struck in the winter of 1969, and we have seen photos of snow from the early 2000s (Figure II-10). The Comaltepec commissariat spoke of snow as being a rare event, but apparently this was not always the case—Musser (1964) noted that according to locals snow cover usually persisted from October through February. Pine–oak–fir forests comprise the first forest zone below the summit and it is a narrow band of this forest on the northern slope that has been badly affected by fire. In the depiction by Wake *et al.* (1992), there is no pine–oak forest here below the pine–oak–fir, whereas Bogert (1968) states that there is such a zone, albeit narrow. Somewhere between 2500 and 2800 m the forest becomes cloud forest down to about 1000 m. Caldwell (1974a) divided this zone into upper and lower at 1650 m ("Vista Hermosa-High Elevations" and "Vista Hermosa-Low Elevations"), but others lump it all into cloud forest. At Vista Hermosa it is noticeably warmer and, even to non-floristically inclined people such as us, there appears to be a shift in vegetation. Between 800 and 1000 m there is another noticeable shift in vegetation from cloud forest to evergreen tropical moist forest.

Fig. II-10. Photograph of snow atop Cerro Pelón in the early 2000s that hangs in the office of the commissariat, Comaltepec.

Writing about northern Oaxaca, Campbell and Duellman (2000:25) said, "we consider the region worthy of Herculean conservation efforts by the Mexican government." This is still the case. What is known of the Sierra de Juárez is magnificent and it is hard to believe that anyone would think that this site is well known. Parra-Olea *et al.* (2005:468) described two salamanders from adjacent ranges, stating:

> "fieldwork in this area, including the nearby Sierra de Juárez, was intensive from the late 1970s to the 1980s when large collections were made and many species were described (e.g., Caldwell, 1974[4]; Campbell, 1982; Papenfuss and Wake 1987). Discovery of our new species indicates that the area is still far from fully explored and that more new species likely exist, although in large portions of the region, forests are being devastated by uncontrolled logging."

Recently, Rovito *et al.* (2012) proved Parra-Olea *et al.*'s (2005) prediction of more species here to be correct by describing yet another new salamander, *Bolitoglossa chinanteca*, from near Vista Hermosa (and which also occurs in the Totontepec AZE site). Campbell *et al.* (1989:491) made a statement that continues to be an apt characterization of the Sierra de Juárez:

> "only one road traverses the region (Mexican Highway 175), and it has been primarily along this road that biologists have made collections. Probably no other region of similar size in México has yielded more new species of amphibians and reptiles in the last few decades, nor remains so superficially known."

Municipality of Santiago Comaltepec, Oaxaca

The municipality of Santiago Comaltepec encompasses 18,366 hectares, of which 10,004 ha are considered communal protected areas (Chapela 2005[5]). It contains

[4] Equals Caldwell (1974b) in our reference list.

[5] The total area was told to us by the community as well. Chapela (2005) lists the union, UZACHI (1993), as a reference for this figure, which is a document we do not possess. Oddly, Chapela (2005) states that UZACHI was formed 10 years prior to his work (i.e., 1995), which would make the union author to a publication two years before the

Fig. II-11. High elevation cloud forest habitat for *Thorius aureus* on the north slope of Cerro Pelón.

three main villages, Comaltepec, La Esperanza, and San Martín Soyolapan. Of these, Comaltepec is by far the largest with 2,500 people, and it is also the municipal seat—in charge of managing the other villages as well as the lands throughout the municipality. We include a brief discussion of La Esperanza because it is the next largest town, falls along Highway 175, and is the locality given for many of the species. San Martín Soyolapan has about 200 people, is far from the highway, and is at perhaps the lowest elevation in the municipality. Little herpetological work has been conducted here and species are probably like that of the rest of lowland, northern Oaxaca. For this reason, we do not discuss San Martín Soyolapan. Among herpetologists, the most famous place in the municipality is likely Vista Hermosa (just north by road of La Esperanza). It consists of just a few houses, but it is the type locality, or a key locality of reference, for multiple species.

Most of our information about Comaltepec comes from the municipal commissariat based in the town of Comaltepec and a police officer from La Esperanza (see Figure II-11 for high elevation forest and Figures II-12 & II-13 for forest near La Esperanza). These two sources differ on the key topics of human population trends and on changes to the climate over time. We had the impression that the commissariat members were trying to paint what they believed to be a rosier picture in both cases. Below, we note other possible reasons for the discrepancies.

The Comaltepec commissariat said that the population of the municipality remains

union was created (probably the result of Chapela's paper taking longer than expected to appear in print). The protected area figure also comes from another publication cited by Chapela (2005) that we do not possess, SAO (2003). The breakdown of land area for the municipality according to SAO (2003), via Chapela (2005), includes 4,210 ha of timber production and 120 ha of agroforestry systems. Another 3,119 ha is devoted to agriculture and livestock (UZACHI 1993).

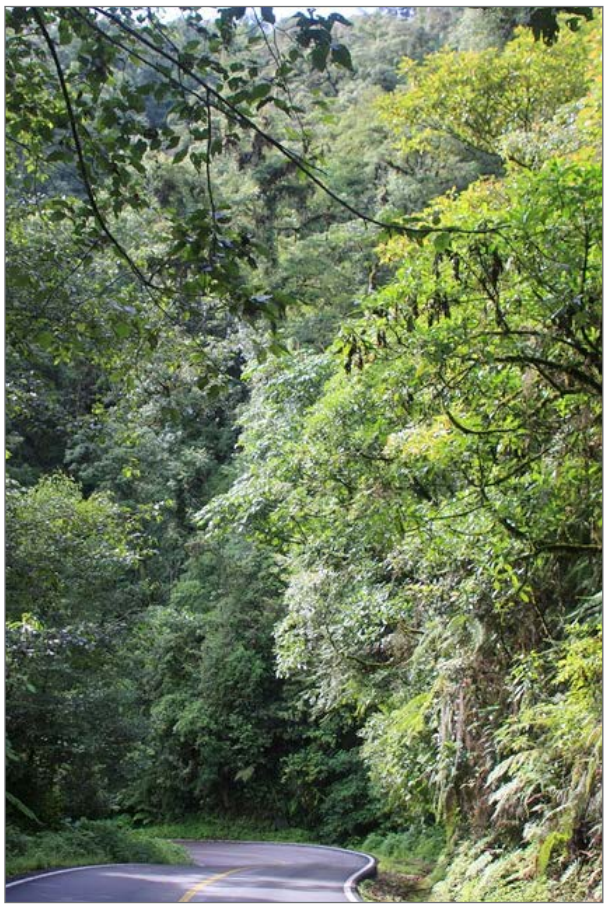

Fig. II-12. Highway 175 near La Esperanza.

stable, or is even growing, despite much emigration. Young men in particular are moving to large cities farther afield and some are even going to the United States. The commissariat says this movement of people has had little effect on the population because those who leave typically return after a year or two. The police officer in La Esperanza, however, told us that the municipal population was definitely in decline. He said small villages, like La Esperanza, were all becoming smaller. He put the total number of people in La Esperanza at 220, while the commissariat said it was 350. The officer said there were 600 people in his town just a few decades ago and that he was certain of the loss because each year La Esperanza conducts a survey to see how many people have left. The final destination for many of these emigrants is Los Angeles, California where as many as 500 people from his town now live.[6] The officer says the effect may be less dramatic in the town of Comaltepec, as many people move there from La Esperanza for work. Also, people serving in municipal government are required to live in Comaltepec.

The people of the municipality are Chinanteco. Everyone in the community speaks the language Chinanteco (or "Chinantec") Alto as opposed to Chinanteco Bajo (from the north, Palantla–Valle Nacional). These two languages are related, but the two groups understand little of each other. Children learn Chinanteco Alto at home, but are taught in Spanish at school. Preschool is bilingual, but later grades are conducted solely in Spanish.

Agriculture and timber sales are the principal economic activities. In 1982, Comaltepec established a management plan for the municipality that sets the

[6] We repeat the numbers here as we obtained them. There is undoubtedly a substantial number of people from La Esperanza now living in Los Angeles, but if the town's population is about four hundred less than it was, then 500 currently in Los Angeles, though possible, seems high.

Fig. II-13. Left: lower montane forest near La Esperanza. Right: a new trail near La Esperanza created by the municipality of Comaltepec.

amount of timber and firewood that can be harvested from designated areas. The plan is renewed every ten years and is due for renewal in 2014.[7] In the year prior to renewal, assessments are made to advise the new management plan. Currently the forest management plan allows for an annual timber extraction of 2000–2800 cubic meters total (that can be sold outside the municipality) plus an additional sum that is allotted for household firewood, which must be used within the municipality. Most of the wood extraction is for firewood and construction. In order to cut trees for personal use, members of the municipality must obtain a permit from the chairman of the commissariat. If trees are cut without permission, the offender is sanctioned with fines or imprisonment.

Conservation Measures

The municipality is recognized as being at the forefront of Community Forest Enterprises (CFEs), whereby the community manages its lands for the long-term benefit of its people (Bray *et al.* 2003; Chapela 2005).[8] Collective management of the municipality lands has its roots in traditional governance. These traditional ways were severely interrupted in 1956 when the federal government awarded a paper mill in Tuxtepec a 25-year concession to the forests of the Sierra Norte.[9] In effect, the

[7] There is a small discrepancy with these dates. If 1982 was the establishment of the management plan and it is renewed every ten years, then the next renewal should be 2012 instead of 2014. Of course, it is possible that the management plan took two years to get underway following its inception.

[8] This paragraph and the one that follows are almost entirely based on Chapela (2005). The two paragraphs provide a mere outline of what is a complex history. We urge anyone who is interested in detailed coverage of this topic to consult Chapela (2005). For an overview of CFEs in Mexico see Bray *et al.* (2003). We recommend Bray *et al.* (2006) for a thorough look at changes to forest management in Mexico.

[9] Referring to the economic zone, which includes not only the Sierra de Juárez, but also the Sierra Mixe.

federal government gave the paper mill, Fábricas de Papel Tuxtepec (FAPATUX), unilateral control of the forests of the Sierra de Juárez for the price of a small stumpage fee. It is not clear to us when FAPATUX began deforesting the Sierra de Juárez in a major way. However, it is clear that local resentment towards the government's arrangement with FAPATUX grew during the 25 years when large clearcuts were being made without input from the communities. In 1981, pressure from the communities kept the logging concession from being renewed for another 25-year period, but this did not cause the deforestation to cease immediately.

Throughout much of the 1980s, Comaltepec and other communities in the Sierra de Juárez fought to gain control of their natural resources. Starting in the early 1990s, the Chinanteco municipality of Comaltepec joined with three nearby Zapoteco communities to work together. In 1995, the communities formed UZACHI (Unión de Comunidades Zapoteco Chinanteca), consisting of: Comaltepec, Calpulalpam de Méndez, Santiago Xiacuí, and La Trinidad.[10] The organization functions so that the communities administer their natural resources. At present UZACHI sells timber to the same mill in Tuxtepec that caused so much uncontrolled destruction just a few decades ago.

The municipality of Comaltepec created a plan of ordinances for land use in 1995. Under this plan portions of the municipality are zoned as reserve, urban, timber harvest, etc. In our opinion, a forward-thinking aspect to this plan was the creation of community protected areas at different elevations to preserve portions of each of the major forest types, regardless of their immediate monetary value. Comaltepec is now implementing an ecotourism plan. The plan consists of five stages. The first stage is the construction of infrastructure. They began this stage in 2008 by opening recreational trails (Figure II-13).

Comaltepec has received a lot of assistance in managing its resources from outside organizations. This has been very beneficial on the whole, although the site's wealth of endemic species does not appear to have been taken into account during planning by any of the organizations. The major external organizations and government agencies that affect the natural resources of the municipality include:

NGOs

ERA (Estudios Rurales y Asesoría) has helped with the implementation of the land use and the forest management plan since 1995.
http://www.era-mx.org/

[10] The municipality of Santiago Comaltepec is by far the largest of the four, with more than 60% of UZACHI's total area.

FSC (Forest Stewardship Council) works for the certification of wood as sustainable. This began in 2000, and each year they send an auditor to verify the origin of the wood.
http://www.fsc.org/

WWF–México has worked here since 2003 with floral and faunal inventory projects. Their visits are sporadic—about every two or three years (see, for example, Briones Salas *et al.* 2006).
http://www.wwf.org.mx/
http://www.wwf.org.mx/que_hacemos/oaxaca/donde_trabajamos/

Government Agencies
CDI (Comisión Nacional para el Desarrollo de los Pueblos Indígenas) funds an ecotourism plan in the municipality that is still in its early stages.

CONAFOR (Comisión Nacional Forestal) is within SEMARNAT and works on a program of reforestation, ProÁrbol.
http://www.conafor.gob.mx/web/

PROFEPA (Procuraduría Federal de Protección al Ambiente) is also within SEMARNAT and is responsible for the commitments given for the legal harvesting of wood.
http://www.profepa.gob.mx/

SEMARNAT (Secretaría de Medio Ambiente y Recursos Naturales) is in charge of making sure that the transport of the wood is legal.
http://www.semarnat.gob.mx

Deforestation in the municipality of Comaltepec is often decried in the zoological literature, and there is almost no mention of the recent improvements to forest management. In fact, the only such mentions of which we are aware are in the Red List accounts of *Thorius macdougalli* (VU), which states: "the rate of deforestation also seems to have substantially decreased compared to earlier years" (Parra-Olea *et al.* 2008c) and *Plectrohyla cyanomma*, which cites personal communication with T. Burkhardt in 2008 that the portion of forest for this species now looks healthy after having been heavily deforested (Santos-Barrera *et al.* 2010). The management of natural resources in the municipality of Comaltepec has definitely improved in the past two decades. Ironically, many of the threatened species in the site have never been rarer. Chytridiomycosis is the major factor in the disappearance of amphibians here (Lips *et al.* 2004). It alone accounts for much of the frog and salamander declines and possibly all of the disappearances (see "Chytridiomycosis" on page 35 for an expanded discussion). A few other threats to amphibian species in this

site are worth noting. The first two may be related: fire and climate change. Another potential threat comes from agricultural pesticides.

Each year there is typically a small fire within the high elevation pine and fir forests that are the most valuable in terms of timber. Uncontrolled fires tend not to occur at lower (wetter) elevations. During the ENSO event of 1983, a fire struck the coniferous forests with an unprecedented scale and intensity. The only other comparable fire occurred in 1998—also as a result of El Niño (for more about the relationship between fire and El Niño, see "Fire" on page 18). The remnant, burned trunks from these fires are evident on the high peaks, mostly on the drier southern slopes where fewer amphibians reside. The fire-stricken areas and others likely to be burned in a large, future fire contain the following species: *Plectrohyla calvicollina*, *P. celata*, *P. cyanomma*, *Thorius aureus*, and *T. boreas*. Fire should be considered a serious threat to them.[11] In 2006, the municipality created a fire brigade and it now has a program of clearing underbrush to reduce the fuel load. In addition, Comaltepec is trying to reforest much of the burned areas. Climate change might increase the likelihood of large forest fires.

The Comaltepec commissariat told us that the climate, timing of the raining season, overall amount of rain, and amount of river flow have all remained the same over time. The La Esperanza police officer, however, said that the climate had changed. According to the officer, the rains and river flow have decreased significantly since the 1970s. In the 1970s, rain occurred throughout most of the year, with only two months in which one could see clear sky. Now it is common to have sun year round, even in the rainy season. The rain in the 10 months of the non-rainy season previously was not very strong, but it was constant rain that lasted most of the day. The rainy season seems to come later now, and the months of light steady rain at other times have been replaced by large *aquaceros* (downpours). He said the soil is not able to absorb this rain, and as a result the aquifer was much lower, many small streams dried up, and the two major rivers in the municipality have much lower water levels. This is a large departure from interviewees in Comaltepec. The policeman seemed to imply that the leaders in Comaltepec may be reluctant to report anything negative, but also said it has always been drier in Comaltepec so the effect may not be as noticeable. The officer was considerably older than the commissariat members. A longer perspective given his age, the fact that he resides at a much lower elevation, and possibly that he is an exceptionally observant person, as evidenced by the complexity of his answer concerning an open-ended, non-leading question about rainfall, might also explain the discrepancy.

[11] Interestingly, we have found only one mention of fire as a possible threat to these high elevation species, which is contained in Campbell and Duellman (2000).

Fig. II-14. Left: frog dead from chytridiomycosis. According to Eric N. Smith, it is likely a female *Craugastor decoratus*. Right: JFL and RCH swabbing a series of amphibians in the Sierra de Juárez site to test for *Bd*.

Agricultural pollutants from the lowlands are a possible threat, but this remains speculative. These pollutants are pesticides that presumably are convected up from the agricultural lowlands in Veracruz into the mountains of Oaxaca (see Box I-1, page 10, for an expanded discussion of this topic).

Species Accounts

Craugastor polymniae, CR (PE) A2ace

Campbell *et al.* (1989) described *C. polymniae* from two specimens they collected on 25–26 July 1983 at 1420 m, 0.8 km north of Vista Hermosa. The two male individuals were calling in a loud, highly variable manner in dense fog following rain (in the previous 24 hours) between 23:00–03:00 hr. One of the frogs was calling from about 3 m high in a tree and the other was about 1 m above the ground. Lips *et al.* (2004) surveyed for *C. polymniae* in 2000, but were unable to locate it. Santos-Barrera and Parra-Olea (2004) speculated that this species has been adversely affected, if not entirely extinguished, by chytridiomycosis and it is currently listed as CR (PE) on the Red List. However, Sean Rovito collected a specimen of *C. polymniae* 15 December 2009 from La Esperanza (IBH 22482; see Rovito 2009).

In the description of the species, Campbell *et al.* (1989) stated that with the discovery of *C. polymniae* there are now three species of the *alfredi* species group[12] known from the Sierra de Juárez. Two of the species, *C. polymniae* and *C. spatulatus* (EN), might even overlap in distribution. This is unusual because nowhere else are members of this group thought to be sympatric. The third species in the Sierra de Juárez, *C. alfredi* (VU), is found below 700 m. *C. polymniae* was at 1420 m and *C. spatulatus* has been found about 200 m above *polymniae* on the same hillside, with

[12] The name of this group was changed to the *bocourti* species series by Hedges *et al.* (2008).

an elevational range of 1621–2235 m in the Sierra de Juárez (Campbell *et al.* 1989). We mention this because we found a dead frog with an extremely high *Bd* load at 1981 m along this road that was clearly from the *bocourti* (formerly *alfredi*) species series and did not belong to any of the three species mentioned (Figure II-14). According to Eric N. Smith (pers. comm.), it is likely a female *C. decoratus* (VU), possibly increasing the range extent of that species, the number of *Craugastor* of the *bocourti* species series in the Sierra de Juárez (to four), and the chances that there is sympatry within the group.[13]

Duellmanohyla ignicolor, EN B1ab(iii)+2ab(iii)

There are eight known species in the genus *Duellmanohyla*; *D. ignicolor* is the only one that exists west of the Isthmus of Tehuantepec. The species did not appear on the 2005 AZE site list and would have fallen between the "Sierra Norte" and "Northern slopes of Sierra de Juarez" sites (Ricketts *et al.* 2005). *Duellmanohyla ignicolor* might have been overlooked because the Red List states that the species is "known only from a few localities" (Santos-Barrera *et al.* 2004). However, all of these localities are easily within a single contiguous forest that falls within the Sierra de Juárez.

Duellmanohyla ignicolor is found in bushes next to, or overhanging, streams in the moist forests along the northern slopes of the Sierra de Juárez at 680–1850 m (Duellman 1970, 2001). Santos-Barrera *et al.* (2004) stated that the species was "relatively uncommon." The most recent record listed on HerpNET (2009) is a UNAM-MZFC specimen found in 1994 by Walter Schmidt Ballardo (MZFC-Herp 6525-1)[14]. Lips *et al.* (2004) reported finding 13 tadpoles in 2000 that they tentatively assigned to *D. ignicolor*; 11 of these had incomplete mouthparts. Presumably it is the work of Lips *et al.* (2004) that the Red List alludes to when it states "larvae with keratinized mouthparts have been found in southern Mexico, which suggests infection with chytridiomycosis"[15] (Santos-Barrera *et al.* 2004).

Ecnomiohyla echinata, CR (PE) A2ace

Ecnomiohyla echinata is known from around 1500 m near Vista Hermosa (Duellman 1970, 2001).[16] Duellman (1961) described *E. echinata* from a male

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[13] Charles Bogert reported *C. decoratus* from the site (Bogert 1968, 1969), but his specimens were considered to be *C. spatulatus* by Campbell *et al.* (1989). The range of *C. decoratus* is now commonly assumed to lie farther to the north from Tamaulipas to central Veracruz and northern Puebla (Santos-Barrera & Canseco-Márquez 2010).

[14] As of 26 May 2014, this specimen record no longer appears on HerpNET. It is still listed (as *Ptychohyla ignicolor* MZFC 6525) by REMIB along with seven other specimens from MZFC, but all information about these records are restricted.

[15] Note that this passage is incorrect as written—keratinized mouthparts are what one would expect from healthy tadpoles.

[16] Santos-Barrera and Canseco-Márquez (2004b) put the elevation at about 2000 m, but

captured by O. C. Van Hyning, 29 April 1960 (no elevation given, Phillips 2003). A female was collected on 3 July 1962 by D. L. Hoyt (no elevation given, UMMZ 2009). These two specimens are commonly considered to be the only ones in existence. For this reason, *E. echinata* is thought to have been last seen in 1962 (Duellman 1970, 2001; Lips *et al.* 2004[17]; Santos-Barrera & Canseco-Márquez 2004b; Delia *et al.* 2013).

Caldwell (1974a), however, referred to three specimens having been collected:

> "Three specimens, two females and a male, of the fringe-limbed hylid, Hyla echinata, are known. Two individuals were found in bromeliads in the forest and a third was taken from a branch of a tree near a stream. Both females are non-gravid and eggs and tadpoles are unknown. The presence of a large amount of webbing in the fringe-limbed hylids has been associated with the ability to glide in Hyla milaria[18] (Duellman, 1970). It is presumed that Hyla echinata also has the ability to glide and that it is an inhabitant of the forest canopy." (pg.59)

The third specimen appears to be one collected by Caldwell "0.8 km S Vista Hermosa" in 1969 (KUH 136702). A number of herpetologists have searched for amphibians near Vista Hermosa, yet *E. echinata* has not been seen in more than 40 years. There have been several interpretations of the fact that this species has been seldom encountered: A) it has always been rare (Santos-Barrera & Canseco-Márquez 2004b), B) it lives high in trees where it is difficult to survey (Duellman 1961), or C) it was wiped out by chytridiomycosis (by implication—Lips *et al.* 2004; Santos-Barrera & Canseco-Márquez 2004b). It is easy to see that several combinations of these potential causes are possible.

It is hard to guess the reason *E. echinata* has not been seen since the 1960s. Lips *et al.* (2004) never directly stated that chytridiomycosis eliminated *E. echinata*. They discussed its disappearance along with other species in the Sierra de Juárez, the assumption being that species in the lowlands were likely extirpated by habitat destruction whereas those in the intact highland areas were probably eliminated by chytridiomycosis. Vista Hermosa, at the boundary of high and low, has certainly

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Vista Hermosa lies at approximately 1470 m, which is consistent with the elevation given for the species by Duellman (1970, 2001).

[17] Lips *et al.* (2004) actually refer to the species as being last seen "prior to 1962."

[18] The spelling of the species name was incorrectly transcribed by Caldwell (1974a) as *milaria* instead of *miliaria*. This species is now usually referred to as *Ecnomiohyla miliaria* (VU) (e.g., Frost *et al.* 2006). Note the change in genus, for it and for *echinata*, follows Faivovich *et al.* (2005).

experienced large-scale habitat destruction. However, this was at its greatest during the late 1970s into the 1980s, at about the same time that *Bd* was likely causing huge declines in amphibian populations. Still, some of the cloud forest was actually never cut, and much of it is now regenerating.

The possibility that *E. echinata* lives high in trees and is simply difficult to locate was raised by Duellman (1961:352): "I have collected at Vista Hermosa on several occasions, but have never found *Hyla echinata*; I suspect it is an inhabitant of the tall trees." Duellman's (1961) description does not contain any specific information about whether the male collected by O. C. Van Hyning was from a tall tree or not. Duellman (1970:348) noted that "one specimen was obtained from a bromeliad, and the other was found on a branch of a tree near a stream in the cloud forest." It is possible that *E. echinata* continues to exist in high bromeliads. However, it is important to note that bromeliads near Vista Hermosa have been examined frequently by herpetologists looking for salamanders without *E. echinata* being encountered. In the description of *Pseudoeurycea saltator* (also present near Vista Hermosa), the salamander is said to be found in bromeliads as high as 8 m above the ground (Lynch & Wake 1989), which means that at least some high bromeliads have been examined.

Because tadpoles of *E. echinata* have not been found, there is uncertainty regarding its breeding microhabitat. The Red List says that the species requires streams to breed (Santos-Barrera & Canseco-Márquez 2004b). Campbell and Duellman (2000) stated that *E. echinata* is a tree-hole breeder, which would make sense given the known requirements of other *Ecnomiohyla* species, but there appears to be no direct evidence that this is the case. The first fringe-limbed frog for which tadpoles were known with certainty (*Ecnomiohyla salvaje* CR) came from water in tree cavities (Wilson *et al.* 1985). Several other species of *Ecnomiohyla* are now known or thought to be cavity breeders or bromeliad specialists (e.g., McCranie *et al.* 2003; Acevedo & Young 2004; Jungfer & Renjifo 2004; Solís *et al.* 2008). This fact could allow for the possibility that tadpoles of *E. echinata* are not tied to streams, but to another microhabitat. At present, there are only two species of hylid frog near Vista Hermosa that are known to breed high in trees, *Bromeliohyla dendroscarta* (CR (PE)[19]) and *Anotheca spinosa* (LC). The former breeds in bromeliads and the latter in tree hollows (Duellman 1970).

[19] The Red List account for *Bromeliohyla dendroscarta* states that it has not been seen since 1974 (Santos-Barrera & Canseco-Márquez 2004c). Provocatively, Hernández-Salinas and Ramírez-Bautista (2012) reported finding four individuals in cloud forest outside the historical range in Hidalgo from surveys in 2007–2008, though nothing more was said about them. We are unable to judge the veracity of these claims, but note that several of the species Hernández-Salinas and Ramírez-Bautista (2012) reported, without comment, are exceptionally rare.

Intriguingly, Delia *et al.* (2013) found multiple individuals of *A. spinosa* in June 2007 during a brief visit to the Sierra de Juárez and heard many more calling. They went on to report:

> "Two additional arboreal breeding hylids remain missing from the Sierra Juarez: *Bromeliohyla dendroscarta* and *Ecnomiohyla echinata* last reported in 1972 and 1962 … We heard numerous individuals of an unidentified hylid calling from bromeliads high in trees near Vista Hermosa, Oaxaca and Huatusco, Veracruz (a historical locality of *B. dendroscarta*, Duellman 2001), but we were unable to capture a frog for identification. These observations indicate that at least one of these arboreal breeding frogs may be extant and we encourage future surveys to explore these sites." (pg.1410 & 1413)

Megastomatohyla mixe, CR B1ab(iii)+2ab(iii)

Megastomatohyla mixe appeared on the 2005 and 2010 AZE lists. The species is also considered to be endemic to the Sierra de Juárez by the current IUCN Red List (Santos-Barrera & Canseco-Márquez 2004d) and Duellman's treatise, *Hylid Frogs of Middle America* (Duellman 1970, 2001). We assume this distribution to be correct, but we discuss two additional records that might extend the range of the species.

In the Sierra de Juárez, *M. mixe* is known from cloud forests on the northern slopes near Vista Hermosa from 1590–1800 m (Duellman 2001). Less than 10 adult specimens have been collected. The first two individuals, from which the description was made, were "found at night on limbs of bushes overhanging a cascading stream" (Duellman 1965:34). Tadpoles of the species are thought to have been collected near Vista Hermosa because they closely resembled a related species that exists elsewhere, *Megastomatohyla mixomaculata* (EN) (Duellman 1970). To our knowledge *M. mixe* was most recently seen (and collected) by Carlos Gónzalez Hinojosa in 1987 and Luis Canseco-Márquez in 1993 (both specimens are housed in the UNAM collection and specific locality data are restricted on REMIB; MZFC-Herp 4398-1 and 13368-1, respectively) (HerpNET 2009; note neither record appears on HerpNET 2014). It is odd that *M. mixe* was never mentioned by Lips *et al.* (2004) because it is another highly threatened species in their Region 3 that is likely to have been adversely affected by chytridiomycosis. It was, however, discussed by Caldwell (1974a), whose transects Lips *et al.* (2004) were retracing.[20]

[20] Another minor oddity is that three of the four University of Kansas records for *M. mixe* appear as being from 4.2 km south of Vista Hermosa (KUH 87110–11, 104183), while the fourth is from 4.2 miles south of Vista Hermosa (KUH 152374) (downloaded 26 May 2014 at http://collections.nhm.ku.edu/HerpsWeb/). It is possible that three of the four entries are from a different locality than the fourth, but because "4.2" is so specific it makes us wonder if in fact all four are from the same locality (which would be either 4.2 *miles* (6.8 kilometers) or 4.2 *kilometers* (2.6 miles) S of Vista Hermosa).

The Smithsonian Institution lists two additional individuals of *M. mixe*, which if verified, would extend the range of the species (USNM 120960, 123694). These specimens were collected by W. Miller in 1944 and 1946 from San Lucas Camotlán, Oaxaca about two decades before Duellman described the species. W. Miller is presumably Walter Miller, the linguist and longtime resident of Mitla in the Oaxaca Valley. A short description of Walter Miller and San Lucas Camotlán appears in Campbell and Duellman (2000). In brief, San Lucas Camotlán is a mountain town in the Sierra Mixe east of Totontepec. It is in one of the last rises before the Isthmus of Tehuantepec and should show biogeographic affinities with the rest of the Sierra Mixe. Campbell visited the area "many years ago" and described it as being drier than the northern slopes of the Sierra de Juárez and Totontepec regions (Campbell & Duellman 2000:24). He also noted that it had been largely deforested.

It would be helpful to know who examined the Miller specimens, and it would be useful for someone to make a thorough study of all of his material from San Lucas Camotlán in the Smithsonian. We say this because it is possible these records for *M. mixe* are valid, which would place the species in both the Sierra de Juárez and the Sierra Mixe.[21] If this proves to be the case, *M. mixe* might no longer be an AZE trigger species. However, the continued existence of *M. mixe* in the Sierra Mixe would need to be verified before changes to either its AZE status or Red List status were entertained.

Plectrohyla calvicollina, CR (PE) B1ab(iii,v)+2ab(iii,v)

Both the Red List (Santos-Barrera & Canseco-Márquez 2004e) and Lips *et al.* (2004) state that *P. calvicollina* has not been seen since 1984. However, we know of no record of the species after 1980. In fact, we know of no record of *P. calvicollina* aside from the two specimens that Toal (1994) used in his description of the species.

The first specimen was an adult male collected by Jonathan A. Campbell at 14:00 hr. on a rock in direct sunlight in the middle of a stream, 17 June 1976 (Toal 1994). The locality was recorded as 2712 m, 1 km N Cerro Pelón. The individual was accompanied by *Plectrohyla celata* and *P. cyanomma*, the latter of which could often be found basking during daylight hours (Campbell & Duellman 2000). Basking is a behavior that some high elevation hylids appear to use as a thermoregulatory aid

[21] Should the Miller specimens of *M. mixe* prove valid, it would also have the advantage of reconciling the species' name with its etymology. Duellman (1965) named the species "mixe" after the Mixe Indians, which he said lived in the same region as the frog. With the exception of the Miller specimens, which are from the heart of Mixe country, all of the records to date (including the holotype and paratype) are from a region of Oaxaca that is decidedly non-Mixe. The section of the Sierra de Juárez where these records originate is Chinanteco. Chinanteco and Mixe are not only distinct peoples that speak different languages; their languages belong to two separate language families (De Ávila Blomberg 2004; INALI 2008; Lewis *et al.* 2014).

(see Duellman & Trueb 1986). The second specimen was an adult female collected by Jonathan A. Campbell and Linda Ford. It was found alive at 21:00 hr. on Highway 175 during a light rain at 2518 m, 9 August 1980.

Plectrohyla calvicollina was sought by Lips *et al.* (2004) in 2000, but was not found. It probably was always an extremely rare species—having never been detected by Caldwell and Robertson during their extensive fieldwork, 1969–1970.

Plectrohyla celata, CR (PE) B2ab(iii,v)

The provenance, both in time and space, of *P. celata* is somewhat confusing. All museum specimens of *P. celata* were collected before Toal and Mendelson (1995) described the frog as being distinct from *Plectrohyla siopela*—a species found 200 km north in Veracruz.[22] Toal and Mendelson (1995) thought *P. celata* occurred in the Sierra de Juárez and also tentatively near Totontepec in the Sierra Mixe (Toal & Mendelson 1995). Subsequently, specimens from the Sierra Mixe were re-assigned to *P. cyclada* (EN) (Campbell & Duellman 2000). With the Sierra Mixe records removed, *P. celata* is said to be confined to the north slope of Cerro Pelón (Duellman 2001). However, there is at least one record from nearby Cerro Machín and three records from Cerro San Felipe (KUH 139837, and KUH 139851–3, respectively). Because all of these localities fall within the Sierra de Juárez AZE site, we include the species here.

Plectrohyla celata is known from cloud forests on Cerro Pelón. The elevational range of the species varies depending on the source. In their description of the species, Toal and Mendelson (1995) put the elevational range at 2640–2670 m. This elevational range comes from the records of *P. celata* by Caldwell (pg.37, 1974b). Oddly, in the same work, Caldwell summarizes the range as 2650–2670 m (pg.24, 1974b), but this might be due to the fact that 2650–2670 m was familiar to the author—being the range of her high elevation Cerro Pelón transect (Caldwell 1974a). Duellman (2001) writes that *P. celata* is found up to 2890 m, and because many of the museum records we have online access to do not list their elevations, we assume this to be correct, but again this is strange because all of these records should have also been available to Toal and Mendelson (1995) when they described the species. We suspect the discrepancy might be due to a reassessment of the elevations of collection localities with better maps or means to determine elevation (as has occurred elsewhere), though we have no direct knowledge that this is the case.

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[22] Toal and Mendelson (1995) initially suspected populations of *P. siopela* in the Sierra de Juárez to be distinct from those in Veracruz simply because they knew of the large numbers of amphibian species with restricted distributions in the Sierra de Juárez. Their taxonomic work confirmed their suspicions. We wonder if there might be other species known from the mountains of central Veracruz and the Sierra de Juárez that warrant similar investigation (e.g., *Bromeliohyla dendroscarta*).

Out of 43 individuals, Caldwell (1974a:24) said the species "was occasionally found on branches above the stream (16 percent of all individuals) but was usually found in crevices of mossy rock walls near the streams."

Plectrohyla celata has not been seen since the 1980s, yet the last date for it is reported differently depending on the authority. Specimens of *P. celata* were first collected by Janalee P. Caldwell and Paul B. Robertson from 1969–1970, when the species was relatively common. A few specimens were also collected in the mid- to late 1970s (Toal & Mendelson 1995). After this, the differences in dates appear. Toal and Mendelson (1995:10) imply that the species has not been seen since 1980, stating "J. A. Campbell (pers. comm.) has visited the type locality of *Hyla celata* a number of times since 1980, and has not located individuals of *H. celata*, *H. calvicollina*, or *H. cyanomma*." This date is repeated by Duellman (2001) as the last date for the species, citing Toal and Mendelson (1995). However, on a different page, Toal and Mendelson (1995:3) state that J. A. Campbell collected a female on 30 June 1981 (UTA A-13380). None of the records used by Toal and Mendelson (1995) in the description of the species, or any records reported in Duellman (2001) or on HerpNET (2014) are from after 30 June 1981. Lips *et al.* (2004) and the IUCN Red List (Santos-Barrera & Canseco-Márquez 2004f) both state that the species has not been collected/recorded since 1984, but neither work gives any details from where this date originates. Because we are unaware of any record after 30 June 1981, we use this as the date for the LYO.

Plectrohyla cyanomma, CR (PE) B1ab(iii,v)+2ab(iii,v)

This species has a miniscule distribution that falls entirely within the Sierra de Juárez. Like *D. ignicolor*, it did not appear on the 2005 AZE list, possibly because the Red List states that the species is "currently known from only three localities" (Santos-Barrera *et al.* 2010). However, the three localities are all very close to one another, within a single forest managed by Comaltepec. Indeed, the high elevation forests of Cerro Pelón and Cerro Humo Chico, the known distribution of the species (Toal & Mendelson 1995; Santos-Barrera *et al.* 2010), are connected with the mountains being just two peaks on the same massif.

Plectrohyla cyanomma is sympatric with *P. celata* and *P. calvicollina*. Compared to *P. celata*, *P. cyanomma* was found more frequently in the pools of streams (Caldwell 1974a). It also preferred deeper pools than *P. celata* (Caldwell 1974a) and was often found at the edge of a pool with its head exposed or totally submerged (Duellman 2001). When disturbed, *P. cyanomma* was said to "swim to the deepest parts of the pools or go under large stones" (Duellman 2001:968). In the 1970s the species was extremely common. Campbell "observed hundreds of *Hyla cyanomma* basking on large boulders by day along a short stretch of stream at the type locality" in 1978 and 1979 (Campbell & Duellman 2000:25).

The Red List reports the elevational range of *P. cyanomma* as 2640–2670 m (Santos-Barrera *et al.* 2010). This is only slightly different than the elevations of 2650–2670 m reported by other researchers (Caldwell 1974a,b; Duellman 2001). Unlike the discrepancy between the lower elevation of *P. celata* (also 2640 vs. 2650 m), we know of no specimen record supporting the lower (2640 m) elevation for *P. cyanomma*. In any case, this difference is trivial. A more substantial discrepancy, however, does exist. In Caldwell's description of *P. cyanomma* (Caldwell 1974b), there is a record listed from 9600 feet (KUH 100507). This record is also listed by Toal and Mendelson (1995). The elevation, 9600 feet, equals just over 2926 m, which, if correct, would be a large elevational range extension. We chose to ignore this record because we did not know what to make of it. It is interesting to us that the specimen has been acknowledged by more than one author, yet at the same time is ignored both in discussion and summaries of elevation by these same authors.

Although *P. cyanomma* was once common throughout the year (Lips *et al.* 2004), the species is now considered Possibly Extinct (Santos-Barrera *et al.* 2010). Lips *et al.* (2004:562) state that "the case for the apparent extinction of *H. cyanomma* is particularly compelling." Campbell and Duellman (2000:25) agree, listing it as an example of a Oaxacan species that was "once locally abundant" but is now apparently extinct. Despite numerous investigations by herpetologists since 1980,[23] it is not known to have been collected after that year (Toal & Mendelson 1995; Duellman 2001; Lips *et al.* 2004; Santos-Barrera *et al.* 2010). Lips *et al.* (2004) cite personal communication with Jonathan Campbell stating that adults of the species have not been seen since 1978, but that tadpoles were found in 1980.[24]

Plectrohyla sabrina, CR A3ce

Caldwell (1974b) described *P. sabrina* from the cloud forests on the northern slopes of the Sierra de Juárez. It is known from 4.2–16.6 km south of Vista Hermosa (KUH 87011, 137038–88, 139816–22, 139825–36) between 1580–2020 m (Duellman 2001). The vast majority of specimens were collected by Janalee P. Caldwell from 1969–1970. There were few additional records in the decade following Caldwell's work in Oaxaca, and according to Santos-Barrera *et al.* (2006) few specimens have been collected since the 1970s. We are uncertain when the species was last seen. The most recent records we know of are those of Lips *et al.* (2004) from 2000. They reported finding 17 tadpoles, which they attributed to *P. sabrina*, nine of which had incomplete mouthparts, presumably due to chytrid

[23] Campbell and Duellman (2000) alone reported that "a thorough search of the area on about a dozen occasions since 1983 has not produced a single adult; furthermore, the larvae—previously so abundant and conspicuous in all of the plunge-pools—are absent" (Campbell & Duellman 2000:25).

[24] Oddly, as noted above, Campbell reported seeing large numbers of adults at the type locality as late as 1979 (Campbell & Duellman 2000).

fungus (Lips *et al.* 2004).

Pseudoeurycea orchileucos, EN B1ab(iii)

When Ricketts *et al.* (2005) was published there were generally thought to be three species of salamanders in the genus *Lineatriton*: *L. orchileucos* (from the Sierra de Juárez), *L. orchimelas* (EN) (Sierra de los Tuxtlas), and *L. lineola* (EN) (Sierra Madre Oriental).[25] Each of these species are still recognized, but the genus *Lineatriton* has since been abandoned and the species are now placed in the genus *Pseudoeurycea*.

We begin by saying a bit about the *Lineatriton* genus. *Lineatriton lineola* was first described as belonging to a monotypic genus by Tanner (1950) that included two populations: one from Sierra de los Tuxtlas and the other from the Sierra Madre Oriental. Parra-Olea and Wake (2001) showed that populations of *P. lineola* from these two regions were not a single species, but they did not formally split the species. Moreover, these two populations of *Lineatriton* were shown to be more closely related to separate species of *Pseudoeurycea* than to each other (Parra-Olea & Wake 2001; Parra-Olea 2002). For this reason, Frost *et al.* (2006) considered the genus *Lineatriton* to be a junior synonym of *Pseudoeurycea* until a thorough revision of *Pseudoeurycea* is conducted, and the Red List follows this taxonomic arrangement (Parra-Olea & Wake 2004).

Pseudoeurycea orchileucos is an elongated salamander that looks very much like the classic "*Lineatriton*." It comes from the Sierra de Juárez, which is isolated from the two populations in Parra-Olea and Wake's (2001) study (i.e., from the Sierra de los Tuxtlas and Sierra Madre Oriental). The first two specimens were collected by Charles J. Cole in June 1964, but these specimens went unnoticed for more than three decades (Brodie *et al.* 2002). Joseph R. Mendelson found another two in 2000. With these four specimens, Brodie *et al.* (2002) described *P. orchileucos* as distinct from the two other known populations of *Lineatriton*.[26] Brodie *et al.* (2002) then formally split the other two populations of *Lineatriton* into two species, keeping *P. lineola* from the Sierra Madre Oriental and naming *P. orchimelas* from the Sierra de los Tuxtlas.

Four additional points about the taxonomy and distribution of the former genus *Lineatriton* are worth mentioning. First, *P. lineola* from the Sierra Madre Oriental might contain more than a single species or at least separate evolutionarily significant units (Parra-Olea & Wake 2001). Second, Canseco-Marquez *et al.* (2000) reported a population of *Lineatriton*-like salamanders from the Sierra Negra

[25] N.B., The two species, *L. orchileucos* and *L. orchimelas* were mistakenly reversed on the 2005 AZE list.

[26] Presumably Brodie *et al.* (2002) submitted their manuscript before the publication of Parra-Olea and Wake (2001) because this latter work was not cited by Brodie *et al.* (2002).

Oriente of Puebla, mountains that lie between the *P. lineola* and *P. orchileucos* populations, which could belong to either species or represent a new one. Third, Sean Rovito informs us that he collected a *Lineatriton*-like specimen (IBH 22562) from near Peña Verde, Santa María Pápalo in 2009. Rovito tentatively identified the specimen as *P. orchileucos* noting that it is either this or an undescribed species, "but it is a juvenile and so I had to base my ID on sequence data only" (S. Rovito, pers. comm.). Finally, the Red List adds a taxonomic note that *P. orchileucos* might not be truly separate from *P. orchimelas* (Parra-Olea & Wake 2004). Although the Sierra de los Tuxtlas is geographically separated from the Sierra de Juárez by a lowland expanse of 150 km, there are amphibian species that occur in both sites. *Pseudoeurycea werleri* (EN) is an example of such a species and it happens to be one of the salamanders that appears to be more closely related to *P. orchimelas* than the latter is to *P. lineola* (Parra-Olea & Wake 2001).

Pseudoeurycea orchileucos is a fossorial, terrestrial species that is usually found beneath rocks or under logs. It is known from cloud forests just south of the towns of Yetla and Vista Hermosa along Highway 175. The last confirmed specimens of *P. orchileucos* were those of Mendelson in 2000. HerpNET (2009) also listed one specimen from the Sierra de Juárez collected in 1996 by Walter Schmidt Ballardo near Vista Hermosa in the UNAM collection that was not used in the description of the species (MZFC-Herp 10546[27]).

The elevational range of *P. orchileucos* is not straightforward. The Red List puts the elevation of the species squarely at 1100 m (Parra-Olea & Wake 2004), which does not adequately capture the range of known specimens. Brodie *et al.* (2002:202) summarized the elevational range as "between at 800 and 1390 m on the humid northern slope of the Sierra de Juárez." This range, however, might also be too limited. On the same page where the lower limit of 800 m appears, Brodie *et al.* (2002) list one of the paratypes as coming from 730 m (KUH 86620). The Ballardo specimen, which Brodie *et al.* (2002) do not mention, is listed on HerpNET (2009) as coming from 1500 m, which would extend the upper elevation. We do not know if the Ballardo specimen was intentionally excluded from analysis by Brodie *et al.* (2002), or whether there is doubt as to the reported elevation of paratype KUH 86620. For this reason we are tentative in placing an elevational range, but we think 730–1500 m is a better reflection of the known specimens.

We did not encounter *P. orchileucos*. It occurs to us after completing our field work that the best way to capture this species would be to set pitfall traps with barriers to guide animals during the summer months (four of the five specimens were found

[27] As of 26 May 2014, this specimen record no longer appears on either HerpNET or REMIB.

Fig. II-15. *Pseudoeurycea saltator* from near La Esperanza.

in either June or July, and we do not know in which month the fifth specimen was collected) (see also the *Thorius smithi* account below). Brodie *et al.* (2002:201) state that Vogt *et al.* (1997) frequently found *P. orchimelas* in "pitfall traps set for scarabid beetles" in the Sierra de los Tuxtlas.

Pseudoeurycea saltator, CR B1ab(iii)

Lynch and Wake (1989) described *P. saltator* as a species found on the north slope of the Sierra de Juárez along a 27-km stretch of Highway 175, south of Vista Hermosa. The species is usually found in bromeliads, "some as much as 8 m above the ground" (Lynch & Wake 1989:15). Other individuals have been encountered under the bark of downed logs and under the logs themselves (Parra-Olea *et al.* 2008d). The elevation of the species is listed as 1500–2000 m (Parra-Olea *et al.* 2008d).

The number of individuals encountered from the 1970s through 1997 was too few to make more than a general comment about the relative abundance over the three decades, but the species did not appear to have changed in abundance during that time (Parra-Olea *et al.* 1999). More recently, however, Parra-Olea *et al.* (2008d) report that the species is decreasing in number even though it can still be found. Sean Rovito informs us that he found the species to be abundant at the type locality in 2010 and that he always found it in bromeliads (S. Rovito, pers. comm.).

We located two individuals of *P. saltator* on 11 November 2008 (Figure II-15). Both individuals were from the same stop along Highway 175, but in different streams. The first one we found was on a small branch a few inches above a cascading creek. One of our field assistants captured the salamander, but it wriggled away—jumping into the creek and burrowing under sharp rocks. At the time, we noted that it flopped around like a newly caught fish. The species is certainly true to its name, which is "Latin for leaper or dancer and refers to the unusual ability of this species

to jump when attempting to elude capture" (Lynch & Wake 1989:15). We managed to hold on to the second individual, which was in a rocky, level strip of ground (small rocks, like scree) along a small stream.

Pseudoeurycea smithi, CR A2ace

Pseudoeurycea smithi was first collected by Hobart M. Smith from Cerro de San Luis in 1935, and described by Taylor as *Oedipus smithi* in a University of Kansas Science Bulletin dated 1938. For this reason the Red List puts the species authority as "(Taylor, 1938)." However, the bulletin was not distributed until 1939, which Taylor, as the journal's editor, regarded as the "actual date of publication," thus "(Taylor, 1939)" is customarily cited as the species authority (e.g., Taylor 1944; Marx 1976; Frost 2014).

The Red List states that this species "may also occur in Sierra de Cuatro Venados, but the specimens have not been validated" (Parra-Olea & Wake 2008). If the Sierra de Cuatro Venados records are excluded, two small polygons are left that both fall within the Sierra de Juárez, such that *P. smithi* would represent an additional trigger species for the Sierra de Juárez site. The editors of the most recent AZE list included *P. smithi* as a trigger species (AZE 2010), and Sean Rovito agrees with this designation, until proven otherwise (S. Rovito, pers. comm.).

Thorius adelos, EN B1ab(iii)

This species is a late entry onto our list of trigger species for the Sierra de Juárez. The Red List account maps this species in three distinct areas: Sierra de Juárez, Peña Verde (corresponding to our Concepción Pápalo AZE site), and the Sierra Mazateca (Parra-Olea *et al.* 2008e). Thus, the species is known from too many sites to be considered a trigger species; however, non-Sierra de Juárez specimens have not been verified and are now thought likely to represent other species (S. Rovito, pers. comm.).

The species' name *adelos* is Greek and means "unseen or obscure" (Papenfuss & Wake 1987:9). True to its name, *T. adelos* has only been found a few times. David Wake has called *T. adelos* "a truly missing in action species" (pers. comm.).

Papenfuss and Wake (1987) described *T. adelos* from a holotype and two paratypes, which they collected between 1973 and 1976. We are aware of only one other specimen, "despite many futile attempts" to find it (Wake *et al.* 2012). Jon Campbell collected a specimen (UTA A-3596[28]) on 28 November 1970 (J. Campbell, pers. comm.), which came from "near the type locality" (Wake *et al.* 2012). Thus, all

[28] Wake *et al.* (2012) incorrectly listed this specimen as "UTAVC A-3956" (J. Campbell, pers. comm.).

records are from cloud forest along Highway 175 from near Vista Hermosa and La Esperanza between about 1500–2000 m (Rovito *et al.* 2013). *Thorius adelos* is an arboreal species and is sympatric with *T. arboreus* near La Esperanza, and with *T. insperatus* and *T. smithi* in the vicinity of Vista Hermosa (Rovito *et al.* 2013).

Thorius arboreus, EN B1ab(iii)

Prior to the publication of Hanken and Wake (1994) there had been only three named *Thorius* salamanders from the Sierra de Juárez (*T. macdougalli, T. pulmonaris,* and *T. narisovalis*). Hanken and Wake (1994) added five. *Thorius arboreus* was one of these, as were the species that comprise the next three accounts (*T. aureus, T. boreas, T. smithi*). In each of these cases, the species had been first collected more than a decade prior to their description. The holotype of *T. arboreus* was collected by D. Darda and P. Garvey, 20 November 1983, but earlier specimens had been found by different people in the 1970s.

Hanken and Wake (1994) report that this is "one of the smallest species of *Thorius*" (pg.578), a genus that is "among the smallest extant tetrapods" (pg.573). *Thorius arboreus* is therefore one of the smallest land vertebrates. It is found from 1500–2200 m along Highway 175 on the north slope of the Sierra de Juárez (Parra-Olea *et al.* 2008f), although HerpNET (2014) contains several records from as high as 2515 m (MVZ 183339–46). This species is often found in bromeliads. At its highest elevations, it is sympatric with *T. aureus* and has been found within 1 km of *T. macdougalli* and *T. boreas* (Hanken & Wake 1994). Parra-Olea *et al.* (2008f) state that *T. arboreus* has always been rare. *Thorius arboreus* was most recently collected 27 October 2010 by Sean Rovito and Dana Lee at "ca. 400 m from MX175 on road to San Isidro Yolox" at 1904 m (S. Rovito, pers. comm.).

Thorius aureus, CR B1ab(iii,v)

Thorius aureus is a magnificent-looking diminutive salamander species. It is a terrestrial species found beneath logs and rocks in intact high elevation cloud forests on the north slope of Cerro Pelón (Parra-Olea *et al.* 2008g) (Figures II-11 & II-16). Parra-Olea *et al.* (2008g) stated of *T. aureus*, "it used to be common, but now seems to have largely disappeared, despite several attempts to locate a population (there has been just one observation in the last few years)." However, Sean Rovito, Itzue Caviedes, Cinthya Mendoza, and Pedro Tenorio found *T. aureus* to be abundant on Cerro Pelón, 27 March 2010 (which is likely the most recent sighting for the species; S. Rovito, pers. comm.). The species is sympatric with *T. arboreus, T. boreas,* and *T. macdougalli* (Hanken & Wake 1994).

Hanken and Wake (1994) reported the elevational range of *T. aureus* as a total of 455 m (2475–2930 m) in the original description. This range was narrowed to 400 m (2600–3000 m) on the current Red List (Parra-Olea *et al.* 2008g). Our three *T.*

Fig. II-16. *Thorius aureus* from the north slope of Cerro Pelón.

aureus individuals were from 2556–2559 m—consistent with the elevational range of Hanken and Wake (1994).

We found all three *T. aureus* at the same locality (i.e., a single stop along Highway 175). The stop consisted of a small stream in an east facing gully, with a lot of rocks, moss, and intact oak forest. There were not many bromeliads here, but there were a few large slightly spiny bromeliad-looking plants on the ground. Upslope, the stream steepened and soon became impassible. The first *T. aureus* was about 0.5–1 m above the stream in a niche carved from the dirt wall. The other two individuals were found on the rocky cliff face along the road beneath a clump of moss. We sought *T. aureus* at a number of stops, but were only successful here.

Thorius boreas, EN B1ab(iii,v)

Thorius boreas is known from in and around Llano de las Flores and at high elevations on Cerro Pelón (Hanken & Wake 1994; Parra-Olea *et al.* 2008h). These two areas are small and separated by approximately 25 km of road (Highway 175), but the populations are likely connected to some extent (J. Hanken, pers. comm.).

The habitat of *T. boreas* is pine–oak–fir forests from 2800–3000 m (Parra-Olea *et al.* 2008h). It is usually found at forest edges under logs or stones. This species has undergone dramatic population declines. The last record for which we have a date is 16 December 2009—found by Sean Rovito, Itzue Caviedes-Solis, and Pedro Tenorio-Lezama at "1.1km N (by rd) of Cerro Pelon mirador on MX175" at 2908 m (IBH 22589) (S. Rovito, pers. comm.).

Thorius smithi, CR B1ab(iii)

Thorius smithi is an extremely rare species, having been found just three times despite much herpetological work within its range (Parra-Olea *et al.* 2008i). The holotype was collected by J. E. Cadle, 14 July 1977, 0.5 miles (by road) SW Vista Hermosa in a pile of woodchips at approximately 1550 m (Hanken & Wake 1994). The paratype was collected by J. R. Mendelson and A. Nieto, 19 July 1992, 1–2 km SW Metates from under a rock at approximately 800 m (Hanken & Wake 1994). Hanken and Wake (1994) stated that this latter elevation is the lowest reported for the genus *Thorius* and that the species ranges from tropical forest to lower montane forest. The most recent specimen was collected by Sean Rovito and Dana Lee on 27 October 2010 from "Oaxaca: 7.9 km N Hwy 175 on road to San Isidro Yolox" at 1274 m (IBH 26615) (Rovito *et al.* 2013).

Hanken and Wake (1994) also described another species, *T. insperatus* (DD), known at the time from a single record collected by J. B. Tulecke, 14 August 1961, from Vista Hermosa beneath a log at approximately 1500 m. Gabriela Parra Olea and David Wake have since found another specimen sometime between October 1997 and May 1998 from 1.2 km N La Esperanza in a bromeliad (IBH 22901). We add mention of this because in the Red List account for *T. insperatus*, a taxonomic note (personal communication from Wake and Hanken) states that this taxon might be synonymous with *T. smithi* (Parra-Olea *et al.* 2008j). However, mitochondrial and nuclear DNA confirm the species is distinct (Rovito *et al.* 2013), thus clearing up the taxonomic uncertainty, which was one of the reasons the assessors listed *T. insperatus* as Data Deficient (Parra-Olea *et al.* 2008j).[29]

We did not find any *Thorius* species near Vista Hermosa. Above we suggest that small pitfall traps might prove useful for locating *Pseudoeurycea orchileucos*. We think the presence of *T. smithi* at roughly the same elevations warrants such an approach.

Notes on the IUCN Red List

We have few comments on the current listings, which is surprising given the number and complexity of these species. At high elevation, the site contains depressingly few frog individuals of any kind. We found only two *Craugastor* species (each represented by a single individual, and one of these was dead) and several individuals of *Exerodonta abdivita* (DD) and *Charadrahyla nephila* (VU). We also located a few tadpoles of *C. nephila* and several other hylid species, but were not confident as to their identities. The current lack of frogs is rather amazing when this region is so diverse. In terms of treefrogs, Campbell and Duellman (2000:25) stated, "as far as we are aware, nowhere in Middle America is the diversity of hylids greater than on

[29] *T. insperatus* would qualify as an additional AZE trigger species for the Sierra de Juárez were it to be listed as either CR or EN on the Red List.

the northern versant of the highlands in Oaxaca, Mexico."

As stated earlier, chytridiomycosis is the greatest threat to frogs and salamanders in the Sierra de Juárez. The condition of the forest habitat throughout much of the site is improving. Readers could interpret this as a signal that many of the listings using the B criterion (B with subcriterion iii – continuing decline of area, extent and/or quality of habitat) should be re-examined. To us, the question is less about whether the habitat is improving or not and more whether we can depend on conservation efforts to continue. The protected zones appear to be secure throughout most of the municipality, but this impression is not substantiated enough to deny use of B(iii). It is unlikely that any of the listings would change because in all cases the populations of these species are declining (subcriterion v – number of mature individuals) even though the habitat is not. We emphasize that the threat of habitat destruction at the higher elevations due to fire has been underestimated.

The listings for *Pseudoeurycea saltator* and *Thorius arboreus* should be reviewed. Both species are listed under identical criteria that are triggered by the EOO, but *P. saltator* is CR, whereas *T. arboreus* is EN. It is true that *P. saltator* has a smaller range size as mapped by the Red List, but the proven ranges for the two are similar. Finally, two *Thorius* species should be reassessed. If in fact *T. adelos* (EN) is only known from four specimens between Vista Hermosa and La Esperanza, the last of which was collected in 1976, then it likely should be CR. *Thorius insperatus* (DD) should also be reassessed. Now that its taxonomic uncertainty has been resolved we think it warrants a listing within a threatened category.

Notes on other species of interest

Charadrahyla nephila, VU B1ab(iii)

Charadrahyla nephila was common in streams near La Esperanza during our visit in June 2009. In one stream this species was found in close proximity to *E. abdivita*. From the Red List maps of the two species it looks as though they might also be found near each other along the Río Aloapan (a large river on the edge of the Sierra Mazateca to the NW of the Sierra de Juárez site; ~55km NW of La Esperanza by air). We found *C. nephila* to be common in the Totontepec AZE site as well (see Figure II-23, page 155).

Exerodonta abdivita, DD

Exerodonta abdivita is a DD frog species from northern Oaxaca. We encountered it just off Highway 175, south of La Esperanza. *Exerodonta abdivita* was described from three individuals collected on 5 June 1983 from the "Río Aloapan, 16.1 km (by road) W Jalapa de Díaz" at 405 m (Campbell & Duellman 2000:4). *Exerodonta abdivita* is said to be known only from the "initial collection" in 1983 (Santos-Barrera 2004). There is, however, a footnote to Campbell and Duellman (2000:7)

stating that Joseph R. Mendelson also collected a specimen of *E. abdivita* on 10 July 1992 from a small tributary of the Río Aloapan "12–15 km (by road) W Jalapa de Díaz, 400–450 m elevation."

Fig. II-17. *Exerodonta abdivita*—also from near La Esperanza.

When our photos of the frog were identified by Jonathan A. Campbell as *E. abdivita* (see Figure II-17), we thought we were adding a new locality for the species and that we were the first to see it in over 15 years. However, unbeknownst to us at the time, Jesse Delia and colleagues had found *E. abdivita* at two localities along Highway 175 in June 2007. One of these was near San Mateo Yetla at 700 m and the other was north of Vista Hermosa at 1,600 m (Delia *et al.* 2013).

We located *E. abdivita* along a stream south of La Esperanza on a humid night following a heavy rain that lasted about two hours. It was calling "creck" at various intervals from a leaf 3 m above the ground next to a stream. Five to ten more of these small frogs were calling at the site, but were not captured. *Exerodonta abdivita* was in close proximity to three individuals of *Charadrahyla nephila*. We also found *C. nephila* the same night at streams both north and south of this locality, but this was the only one where we saw or heard *E. abdivita*.

Pseudoeurycea juarezi, CR A2a+4a

The Red List range description says that "this species occurs between Cerro Pelón and Vista Hermosa in the Sierra de Juarez" (Parra-Olea *et al.* 2008k), which would qualify it as an additional AZE trigger for this site. However, the Red List map shows a *P. juarezi* polygon that lies within the Totontepec site that is not mentioned in the species account (Parra-Olea *et al.* 2008k). Gabriela Parra Olea has since informed us that the salamanders found at Totontepec were provisionally assigned to *P. juarezi*, but that new material and DNA testing would be needed for confirmation. If that population is a separate species, then *P. juarezi* would qualify as an additional AZE trigger for Sierra de Juárez.[30]

[30] As noted above, the same issues about AZE trigger status for *P. juarezi* pertain to *P. smithi*. Although in this latter case the assumption appears to be that the populations from Sierra de Cuatro Venados are not the same as those in the Sierra de Juárez (Parra-Olea & Wake 2008).

Fig. II-18. *Pseudoeurycea juarezi*.

Pseudoeurycea juarezi was not located in the 1997 transect survey reported by Parra-Olea *et al.* (1999), yet the species was "abundant" in the 1970s (J. Campbell, pers. comm.). The Red List account states that the species "has undergone dramatic declines and is now uncommon. Only one individual has been located in recent years (c. 2000)" (Parra-Olea *et al.* 2008k). We found this species on two occasions (Figure II-18). We first encountered it on the night of 4–5 September 2008, when we located 19 individuals. All of the individuals we found were along one of the few high elevation side roads off Highway 175. The night was clear, with a nearly full moon and little wind. Most of the salamanders were in plain view on leaves of low vegetation that bordered the dirt road about half a meter to a meter off the ground. The only other time we encountered numerous salamanders in a single night was at Concepción Pápalo, when *Pseudoeurycea aurantia* were positioned in a similarly visible manner (see page 97). Presumably such occurrences of some *Pseudoeurycea* salamanders happen when conditions are just right (seasonal and/or weather). On the night of 11 November 2008, we found another three individuals at a slightly higher elevation. We are not convinced that the Red List status of this species should change due to our finds. *Pseudoeurycea juarezi* is still extremely rare, and there is little doubt that its numbers are greatly diminished from their former levels.

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Table II-2. Amphibians encountered at Sierra de Juárez (4–7 September 2008; 10–12 November 2008; 24–26 June 2009). AZE species are marked with an asterisk (*).

Species	Date/Time	Lat/Long	Elev
Charadrahyla nephila	25 June 2009	N17 36.686 W96 22.435	1691 m
Charadrahyla nephila	25 June 2009	N17 36.686 W96 22.435	1691 m
Charadrahyla nephila	25 June 2009	N17 36.686 W96 22.435	1691 m
Charadrahyla nephila	25 June 2009	N17 36.110 W96 22.996	1804 m
Charadrahyla nephila	26 June 2009	N17 35.408 W96 23.616	1989 m
Charadrahyla nephila	26 June 2009	N17 35.408 W96 23.616	1989 m
Craugastor sp1	5 September 2008	N17 35.230 W96 29.516	2443 m
dead frog (*Craugastor* sp2)	11 November 2008	N17 35.396 W96 23.822	1981 m
Exerodonta abdivita	25 June 2009	N17 36.686 W96 22.435	1691 m
Pseudoeurycea juarezi	4 September 2008	N17 35.284 W96 29.454	2445 m
Pseudoeurycea juarezi	4 September 2008	N17 35.284 W96 29.455	2446 m
Pseudoeurycea juarezi	4 September 2008	N17 35.269 W96 29.452	2448 m
Pseudoeurycea juarezi	4 September 2008	N17 35.269 W96 29.453	2449 m
Pseudoeurycea juarezi	4 September 2008	N17 35.269 W96 29.454	2450 m
Pseudoeurycea juarezi	4 September 2008	N17 35.248 W96 29.466	2447 m
Pseudoeurycea juarezi	4 September 2008	N17 35.248 W96 29.466	2447 m
Pseudoeurycea juarezi	4 September 2008	N17 35.230 W96 29.515	2442 m
Pseudoeurycea juarezi	4 September 2008	N17 35.228 W96 29.579	2436 m
Pseudoeurycea juarezi	4 September 2008	N17 35.228 W96 29.579	2436 m
Pseudoeurycea juarezi	5 September 2008	N17 35.237 W96 29.583	2436 m
Pseudoeurycea juarezi	5 September 2008	N17 35.126 W96 29.558	2424 m
Pseudoeurycea juarezi	5 September 2008	N17 35.127 W96 29.571	2420 m
Pseudoeurycea juarezi	5 September 2008	N17 35.127 W96 29.571	2420 m
Pseudoeurycea juarezi	5 September 2008	N17 35.127 W96 29.571	2420 m
Pseudoeurycea juarezi	5 September 2008	N17 35.127 W96 29.571	2420 m
Pseudoeurycea juarezi	5 September 2008	N17 35.129 W96 29.606	2420 m
Pseudoeurycea juarezi	5 September 2008	N17 35.114 W96 29.613	2421 m
Pseudoeurycea juarezi	5 September 2008	N17 35.142 W96 29.547	2437 m
Pseudoeurycea juarezi	11 November 2008	N17 35.287 W96 29.840	2550 m
Pseudoeurycea juarezi	11 November 2008	N17 35.136 W96 30.751	2842 m
Pseudoeurycea juarezi	11 November 2008	N17 35.132 W96 30.745	2847 m
*Pseudoeurycea saltator**	11 November 2008	N17 35.364 W96 23.802	2004 m
*Pseudoeurycea saltator**	11 November 2008	N17 35.402 W96 23.599	1991 m
*Thorius aureus**	11 November 2008	N17 35.292 W96 29.841	2556 m
*Thorius aureus**	11 November 2008	N17 35.271 W96 29.789	2559 m
*Thorius aureus**	11 November 2008	N17 35.271 W96 29.789	2559 m

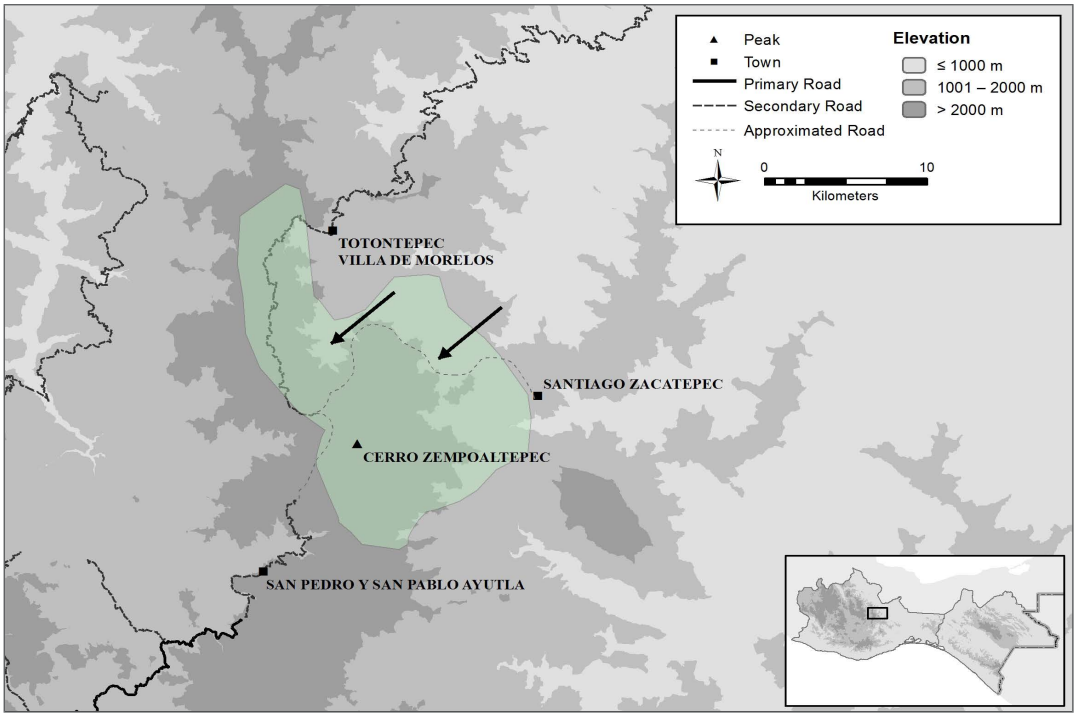
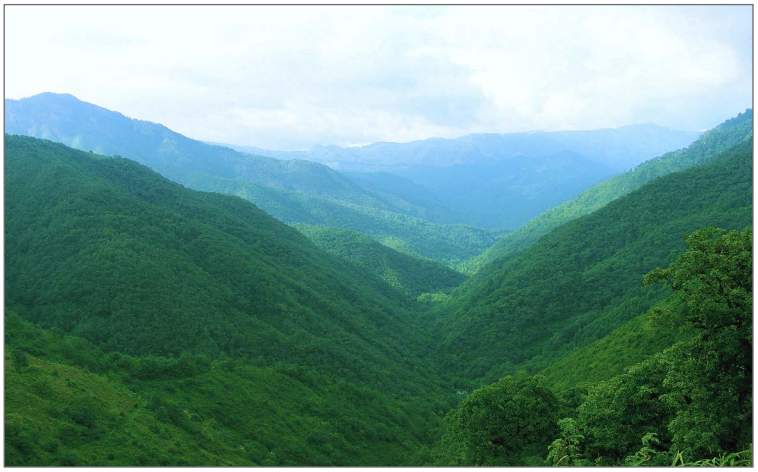


Fig. II-19. Map of the Totontepec AZE site. The green polygon represents the extent of the site. Two black arrows indicate where we located AZE trigger species (from left to right: *Plectrohyla psarosema* [uncertain, see text for details], *P. calthula*).

Totontepec



Trigger Species	Last Year Observed
Frogs	
Plectrohyla calthula, CR B1ab(iii,v)	2012
Plectrohyla psarosema, CR B1ab(iii)	1978 (possibly 2009)
Salamander	
Pseudoeurycea aquatica, CR (PE) B1ab(iii)+2ab(iii)	1978

Located: *Plectrohyla calthula* – 1 adult and several tadpoles. *Plectrohyla psarosema* – likely located 2 metamorphs and several tadpoles.
Visits: 5–6 June 2007 (prior to our grants), 7–10 November 2008, 1–3 June 2009, 22–24 July 2009.
Conservation Contact: None.

Non-amphibian AZE Trigger (not covered in this site account)
Mammal
Habromys lepturus, CR B1ab(iii)
Microtus umbrosus, EN B1ab(i,ii,iii)+2ab(i,ii,iii)[1]

Delineation

We recommended that the three sites from 2005 ("Totontepec I," "Totontepec II," and "Totontepec III") be combined into a single, enlarged site. "Totontepec I" was triggered by *Plectrohyla calthula*, "Totontepec II" by *Plectrohyla psarosema*, and "Totontepec III" by *Pseudoeurycea aquatica*. The separation of *Plectrohyla psarosema* and *Pseudoeurycea aquatica* into two sites was illogical because the two species were

[1] Although the Red List range map for *Microtus umbrosus* is quite large (de Grammont & Cuarón 2008), all known records appear to be within this AZE site (see Goodwin 1969; Cervantes *et al.* 1994; Frey & Cervantes 1997).

discovered on the same night in 1978 near each other in a stream close to the village of Totontepec (Campbell & Duellman 2000; Wake & Campbell 2001). Neither species has been located with certainty since that time.

Plectrohyla calthula was found near Totontepec as well, but not in the same stream. Meik *et al.* (2005) rediscovered it in 2001, finding tadpoles and metamorphs in the municipality of Zacatepec, which is adjacent to the municipality of Totontepec on the opposite side of the valley—still broadly facing the Caribbean. In 2009, we found an adult and tadpoles of *Plectrohyla calthula* in the municipality of Zacatepec (at a locality near to the one reported by Meik *et al.* 2005) and we might have located metamorphs and tadpoles of *Plectrohyla psarosema* in a stream within the municipality of Totontepec. We recommended that the three Totontepec sites be combined under the name Totontepec, and that this include the entire valley and Cerro Zempoaltepec, which lies on the valley edge. This mountain could contain these amphibians and is the only locality for the Slender-tailed Deer Mouse (*Habromys lepturus* CR).[2]

Background

The town of Totontepec Villa de Morelos is situated at 1830 m in the Sierra Mixe of Oaxaca. The most obvious way to reach Totontepec is by paved road from the Oaxaca Valley. To do so, one drives through the town of Ayutla (see page 163). From Ayutla the road towards Totontepec is largely uphill until you reach a ridgetop, where there is a split in the road with one direction that heads to Totontepec and the other towards the town of Zacatepec. At this point a new valley opens up that drains to the Caribbean. It is noticeably wetter throughout most of this valley than on the Ayutla side, and the natural vegetation is humid, oak-dominated cloud forest (Figure II-20). From the road split it takes about 30 minutes by car to reach the town of Totontepec. This section of road twists and turns in many different directions, but generally one decreases in elevation when moving from the split towards Totontepec.

The municipality of Totontepec, including surrounding villages such as Santa María Huitepec, has 4,780 inhabitants. The population is declining because many people emigrate to Mexico City, the cities of Oaxaca and Veracruz, and the United States. Most people speak Spanish as well as the indigenous language, Mixe. There is an agreement between the teachers and parents in the town that the school children be instructed in Spanish, while the parents teach children Mixe at home. If the parents are not fluent in Mixe, the grandparents will teach it.

The principal economic activity in Totontepec is agriculture. People mainly grow

[2] We include *H. lepturus* as a trigger species for the Totontepec AZE site. AZE (2010) mistakenly listed it as a trigger for the Sierra de Juárez site.

Fig. II-20. Montane forest within the Totontepec AZE site. We found *Plectrohyla calthula* in the stream on the right.

beans and corn (the latter is planted in the traditional manner using a pole to make holes for seeds). Almost everything that is grown is for local consumption. Some people (perhaps 10%) plant coffee. It has been 13 years, however, since coffee was seriously cultivated because there is no longer a market for it. A few people also cultivate sugar cane to make spirits.

The Meik *et al.* (2005) locality for *Plectrohyla calthula* falls within the municipality of Santiago Zacatepec and is on the opposite side of the large winding valley from Totontepec. In November 2008, when returning home from Totontepec where we had been searching for *P. calthula*, we made a quick detour towards Zacatepec to scout for places to look for the species on future trips. From the road we saw a river that was well forested. We returned to this locality in summer 2009 and saw a large patch above the river that had been cleared (Figure II-21). We found *P. calthula* in the river just downstream from the forest clearing, but due to time constraints we were unable to talk to inhabitants of Zacatepec about conservation and forest management. Meik *et al.* (2005) noted that forests were largely fragmented and being destroyed at an alarming rate near Zacatepec. This agrees with our cursory experience.

Fig. II-21. The Totontepec AZE site, looking down the valley towards the Caribbean (top left). Deforestation within the Totontepec AZE site (top right). Agriculture on steep slopes is not uncommon within Totontepec (bottom left). New burn at the top center is just above where we found *Plectrohyla calthula* (bottom right).

Conservation Measures

The road to Totontepec became "passable by motor vehicle only sporadically" in the late 1970s (Campbell & Duellman 2000:2). Jonathan Campbell informs us that:

> "The first attempt at paving the road to Totontepec must have been in 1979 or 1980. It clearly was not paved during my first few trips into the area in 1978. It was little more than a narrow, mountainous ribbon of mud with landslides and washouts around practically every turn. We thought we might lose our lives on several occasions." (J. Campbell, 11 July 2014)

It is tempting to view Totontepec as a paradise prior to Campbell's visit and an ecological disaster shortly thereafter. This might be true in terms of the existence of species, however, Campbell and Duellman (2000:25) were quick to point out

that "the area around Totontepec was already cleared at the time of our first visit in 1978."

Fig. II-22. Authors with Cesar López Alcántara, former mayor of Totontepec.

Ecological disasters are often difficult to comprehend on many levels. In Totontepec, one can see a community that lost a vital resource (water) due to reckless deforestation (Figure II-21). Species were also lost locally and perhaps globally. In this situation, the underlying reason for the destruction is obscure. Before the modern road to Totontepec was finished, the area around the then village was not intact. It is likely that some deforestation had occurred well before the road's completion. As evidence for this, we note that the type locality for *Plectrohyla calthula* is from a stream in secondary forest which ran along a grassy hillside, neither habitat of which is likely to occur "naturally" in the humid environs surrounding the town of Totontepec. Neither habitat would also be likely to appear within a year or two of deforestation; secondary forest takes time to grow, and cleared grassy slopes tend to be noted as being new until the stumps and debris disappear. Nevertheless, following the arrival of the road deforestation around Totontepec rapidly accelerated for no clear reason.

The former mayor of Totontepec (an office to be held for a single year, in this case 1982), Eli Cesar López Alcántara (69 years old), told us that the land was being cleared to plant corn (Figure II-22). The timber was not sold and, while some was used locally, most of the forest was simply cut and burned. The odd part is that Mr. Alcántara stated that the people clearing the land were from Totontepec and that the subsequent crops were almost entirely consumed by the people of Totontepec. To this day, crops are generally not sold outside the municipality. So why did the road create such mayhem in the land management around the town? It is not credible to assume that the road's completion was merely a coincidence, even if deforestation had occurred in prior times. If the causes of the deforestation remain obscure, however, the detrimental effects are well known.

Totontepec's destruction was graphically recounted by Wake and Campbell (2001). When they returned to the type locality of *Plectrohyla psarosema* and *Pseudoeurycea aquatica* in 1979, one year after the initial discovery of these species, the forest on one side of the stream had been cut down to the water's edge and the stream contained burned logs and ashes. By 1983 and 1984 the situation had become even

worse, with the entire area "cleared and the stream badly silted" (Wake & Campbell 2001:513). During all three of these return visits the amphibians were sought without success despite "many" nights of searching. They concluded that the area was so heavily degraded that it was "highly improbable" that *Pseudoeurycea aquatica*, and presumably *Plectrohyla psarosema*, survived near the type locality (Wake & Campbell 2001:513). A similar conclusion was reached by Ustach *et al.* (2000) concerning the continued existence of *Plectrohyla calthula* at its type locality. They write that when Joseph R. Mendelson visited in 1992, he "found virtually no remaining forest in the region. It is unlikely that this species persists in this area" (Ustach *et al.* 2000:248–249).[3]

At different AZE sites, we often ask locals whether they have seen any evidence of changes to the climate. Sometimes people have noticed that the amount of rainfall has changed or the rainy season is different. In Totontepec, the question becomes an invitation to discuss the loss of water following the deforestation in the late 1970s and early 1980s. Simply put: when virtually all the forests were cleared, the streams dried up. Now, some 30 years later, much of the west side of Totontepec has been reforested and the water has returned, whereas to the east of town, the land is still cleared and there is almost no water. We found the type locality for *Pl. psarosema* and *Ps. aquatica* (on the west side) to be in amazing shape. Upon reading this section, both Jon Campbell (who visited the site in 2012) and Sean Rovito (visiting in 2013) commented on its recovery. Campbell's exact words to us were:

> "although not back to its original pristine state, the stream constituting the type-locality has made a somewhat remarkable comeback as of 2012. A luxuriant secondary growth borders and shades the stream and all of the mud and silt that was so apparent immediately after the region was cleared have now disappeared revealing the original gravel bottom of the stream." (J. Campbell, 11 July 2014)

There is very little forest in the region that has never been cut and none of the uncut areas are near the road or near rivers. The forests around Totontepec are managed to some degree and there are different areas zoned for extraction. In general, to the west of town the forests are being regrown and to the east forests are unregulated. There is no comprehensive plan for buffering streams and in some areas trees along a river can be cut. All wood consumption is solely for the community such that no wood is sold to the outside. Timber is extracted with permission from the commissioner and each family receives one dumptruck load of firewood a year (it

[3] A similar statement from Mendelson can be found in Toal and Mendelson (1995).

is not clear whether this is cut at one time or throughout the year). In addition, townspeople can ask for permission to take particular pieces of wood. A few non-timber forest resources are harvested. Mushrooms from the forest are taken, and about 10–15% of the people know which of these are edible. The "popocho" herb is brewed and consumed as an intoxicant. This herb is sold (along with a few others) outside Totontepec.

No government agency works with forests in Totontepec, but apparently for the two years prior to our visit a Canadian entity has been paying a million pesos annually to conserve forest, but we were unable to learn who this is.

Species Accounts

All three trigger species were discovered by Jonathan A. Campbell in April 1978. Soon after these discoveries, the type localities were, by all accounts, destroyed. We discuss this destruction in the previous section and confine ourselves here to the published accounts concerning the provenance of known specimens.

Plectrohyla calthula, CR B1ab(iii,v)

Plectrohyla calthula was discovered on 8 April 1978 from a small stream in secondary cloud forest east of the town of Totontepec (Ustach *et al.* 2000). Traveling to Totontepec by road from Oaxaca City, one passes through town to reach the east side, which is (generally) lower in elevation than the west side. Twenty-one adults of the species were found along the stream between 1798–1830 m in elevation. One hundred tadpoles were also collected at the type locality in "springs emanating from a grassy hillside" (Ustach *et al.* 2000:244). Neither coordinates nor mileage from Totontepec were given in the species' description for the type locality. Other amphibians recorded from the locality were *Craugastor berkenbuschii* (NT) and *Pseudoeurycea boneti* (VU) (Ustach *et al.* 2000).

Despite various subsequent collecting trips to the Totontepec region, *P. calthula* went undetected for nearly two decades.[4] On 21 September 2001, a series of tadpoles and a single metamorph were located on the opposite side of the valley, west of Zacatepec (Meik *et al.* 2005). The published locality for these specimens was 17.190° N 95.987° W with an elevation of 1360 m. However, these coordinates are actually at 2000 m in elevation. We have since been informed that the elevation of 1360 m along the road west of Zacatepec is correct, but the published coordinates are not (E. Smith, pers. comm.). The correct coordinates are most likely 17.179° N 95.943° W. We know of no other records of the species.

We found an adult *P. calthula* and what were likely tadpoles of it on 3 June 2009 at

[4] The last adult specimen records of which we are aware are from 1978, although Campbell reported seeing them as late as 1984 (Campbell & Duellman 2000).

1637 m (Figure II-23). This is the first record of which we are aware for an adult *P. calthula* in a quarter century. The river where we found the frog lies at the bottom of a large waterfall and is known as San Pedro. It is approximately 21 km by road northeast from the ridge-top road split that goes in the other direction towards Totontepec. The river appears to be well-known among locals because it is the site of an abandoned silver mine. RCH found the *P. calthula* adult at night in a patch of secondary forest on a branch about two meters above a small tributary. A single adult *Charadrahyla nephila* was found nearby (Figure II-23), as well as numerous tadpoles of two species—presumably *C. nephila* and *P. calthula*. Also close by was an amphibian egg mass on a leaf directly above the stream belonging to another species (Figure II-23). In the summer of 2012, Jon Campbell found "several small choruses of *Plectrohyla calthula*" (pers. comm.).

Plectrohyla psarosema, CR B1ab(iii)

Plectrohyla psarosema is known from five adult specimens, all of which were collected on 5 April 1978 from a single locality. The type locality is "3.6 mi (= 5.8 km) W (by road) Totontepec" at 2103 m, 17°14'24" N, 96°03'36" W (Campbell & Duellman 2000:11) (note: these coordinates refer to the town of Totontepec, not the collecting locality). In 1978, the type locality stream ran through pristine cloud forest. At the height of the dry season it was 1.5 m wide with a series of waterfalls and plunge pools that were up to a meter deep. Two of the individuals were found on leaves along the stream, and the other three were between boulders in the splash zone of waterfalls (Campbell & Duellman 2000). Two other frogs were encountered in close proximity to *P. psarosema*: *Charadrahyla nephila* and *Plectrohyla cyclada* (Campbell & Duellman 2000).

We likely found two metamorphs and several tadpoles of *P. psarosema* (Figure II-24). The animals were found in a small, shallow pool next to a large river located in Santa María Huitepec (a village within the Totontepec municipality). We came across these individuals in broad daylight (2 June 2009). We are uncertain about the identity of these animals because we did not collect them for comparison to museum specimens and we have to rely on photographs. Also, because metamorphs and tadpoles of *P. psarosema* have never been found there is uncertainty as to what they would look like. We can say that the very small size of the metamorphs coincides with *P. psarosema* being the smallest member of the *Hyla bistincta* group[5] (Campbell & Duellman 2000). The reddish eyes and general coloration also accord

[5] This may not be true now that the *Hyla bistincta* group (as outlined by Duellman 2001) has become the *Plectrohyla bistincta* group (adding to it the traditional *Plectrohyla* [*sensu stricto*, Duellman & Campbell 1992] and some of the species formerly in the *H. miotympanum* and *H. pictipes* groups [Duellman 1970, 2001]; see Faivovich *et al.* 2005). We agree with Meik *et al.* (2006:308), who, in their description of *Plectrohyla miahuatlanensis*, stated: "a detailed study of interspecific relationships within *Plectrohyla* would almost certainly provide a major contribution to Middle American biogeography."

Fig. II-23. First adult of *Plectrohyla calthula* seen in 25 years (upper panels). Egg mass west of Zacatepec at same locality as *P. calthula* (lower left). *Charadrahyla nephila* found near *P. calthula* (lower right).

well with *P. psarosema*. The only other frog we are aware of that is known from the valley as a whole that could be confused in eye color and size with *P. psarosema* is *P. cyclada*. In adults the difference between these two species should be obvious in several ways. Most easily, the difference would come down to coloration and to the fact that *P. psarosema* does not have a visible tympanum whereas *P. cyclada* does. Although our metamorphs lacked a visible tympanum, we were uncertain whether this feature would be visible in *P. cyclada* at this stage of development.

We sent several photos to William Duellman for his opinion of the identity of our find. He replied:

> "I have closely examined the images of the metamorphic hylid and am unsure of its identity, I agree that it is most likely *Hyla* (now *Plectrohyla*) *psarosema*. The reddish orange eye is like that species but lacks the black flecks, which may develop at a later stage. However, the reddish orange iris shown in your photos could

Fig. II-24. Metamorph of an unidentified frog species from Santa María Huitepec that is likely *Plectrohyla psarosema*—a species that was last seen in 1978.

develop into the copper iris characteristic of *Hyla cyclada*. The absence of a tympanum suggests *H. psarosema*; usually by this stage a tympanum is visible. But, let us not eliminate a third possibility – an undescribed species!" (W. Duellman, 10 June 2009)

It is a considerable hike to reach the locality where we found these animals, and the locality is far from secure (Figure II-25). We retraced our steps on 22–24 July 2009, but we were unsuccessful at locating the frog. Of course, if they are indeed *P. psarosema*, the implications for conservation would be large. To our knowledge, there is no record of this species since 5 April 1978, and its type locality was subsequently destroyed. We found no other amphibians near these animals.

Pseudoeurycea aquatica, CR (PE) B1ab(iii)+2ab(iii)

Pseudoeurycea aquatica is the only aquatic, tropical plethodontid salamander. We failed to locate it. In fact, all information about *Ps. aquatica* comes straight from its description by Wake and Campbell (2001). It is known from just three specimens collected during two nights of field work (early morning hours on 5 and 9

Fig. II-25. Waterfalls and plunge pools are a common feature of the headwaters of the Río La Lana in the Totontepec AZE site (top left). Plunge pool in Santa María Huitepec where we found the metamorph from the previous page; note the destruction to the right (top right). New burn next to the Río La Lana (same locality as upper right) (bottom left). Santa María Huitepec has a trout hatchery that is "secure." However, these two shots show that trout do escape (bottom right).

April 1978). The type locality for *Ps. aquatica* is the same as that for *Pl. psarosema* (discussed above), so the two additional frog species found along with *Pl. psarosema* (listed above) would have been present when *Ps. aquatica* was discovered.

Pseudoeurycea aquatica is considered to be strongly nocturnal and was only seen in plunge pools that were up to about 5 m across and a meter deep along one stream. Although only three individuals were collected, Wake and Campbell (2001) noted that about six additional individuals were seen but escaped capture. The species was said to be quick and agile in water and "when first seen, individuals were resting on sand or gravel at the bottom of pools, but reacted to the beam of a flashlight within several seconds and tried to flee beneath huge boulders" (Wake & Campbell 2001:513). Campbell repeatedly searched several other streams above and below the type locality, but did not encounter *Ps. aquatica* elsewhere (Wake & Campbell

2001). The only other salamander reported from the type locality was *Pseudoeurycea bellii* (now referred to here as *Ps. boneti*, see Parra-Olea *et al.* 2005), although at higher elevations "several other species of *Pseudoeurycea* and *Thorius* were collected" (Wake & Campbell 2001:513). In the years since its discovery, there have been many attempts to relocate *Ps. aquatica*; all of these have proven unsuccessful and Parra-Olea and Wake (2008) state that the species is likely extinct.

Should *Ps. aquatica* still exist near Totontepec, trout is a possible threat to it. Trout are unlikely to be at the type locality for *Ps. aquatica* (there are large waterfalls at various points along the stream that would prevent trout from reaching the type locality from the rivers lower in the valley; J. Campbell, pers. comm.). However, should *Ps. aquatica* exist in other streams within the valley, it might well encounter the introduced fish. Trout have escaped into the wild in streams near Totontepec as well as near Santa María Huitepec (a village within the municipality of Totontepec), where we have seen them ourselves (Figure II-25). These fish tend to live in plunge pools. Because trout are predatory they would have severe detrimental effects on salamanders if they happen to co-occur. Introduced trout are known to be a major threat to a number of amphibians globally (Kats & Ferrer 2003; Vredenburg 2004) and to several salamanders in the genus *Ambystoma* in Mexico (e.g., Shaffer *et al.* 2008a,b).

Notes on the IUCN Red List

Pseudoeurycea aquatica is appropriately listed as CR (PE) by IUCN. The listing of *Pl. psarosema* as CR should not be altered on the possibility (or, as we would like to think, probability) of its rediscovery. Even if our find proved to be *Pl. psarosema*, we suspect the listing of the species would not change. However, while we agree with its designation as CR, it should, like *Ps. aquatica*, be flagged as Possibly Extinct for the time being. *Plectrohyla calthula* is listed as CR by IUCN and this is the proper listing.

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Table II-3. Amphibians encountered at Totontepec, 7–10 November 2008 and 1–3 June 2009. AZE species are marked with an asterisk (*). We also found *Pseudoeurycea boneti* from a stone wall in the town of Santa María Huitepec (2 June 2009), but did not record its coordinates.

Species	Date	Lat/Long	Elev
Charadrahyla nephila	7 November 2008	N17 15.263 W96 03.318	2141 m
Charadrahyla nephila	7 November 2008	N17 15.255 W96 03.323	2148 m
Charadrahyla nephila	7 November 2008	N17 15.261 W96 03.338	2158 m
Charadrahyla nephila	8 November 2008	N17 15.862 W96 02.925	2048 m
Charadrahyla nephila	8 November 2008	N17 15.862 W96 02.925	2048 m
Charadrahyla nephila	9 November 2008	N17 16.011 W96 02.604	2050 m
Charadrahyla nephila	9 November 2008	N17 16.011 W96 02.604	2050 m
Charadrahyla nephila	3 June 2009	N17 11.399 W95 59.133	2008 m
Charadrahyla nephila	3 June 2009	N17 10.812 W95 58.183	1637 m
Craugastor sp1	8 November 2008	N17 15.867 W96 02.947	2074 m
Craugastor sp1	8 November 2008	N17 15.863 W96 02.945	2037 m
*Plectrohyla calthula**	3 June 2009	N17 10.812 W95 58.183	1637 m
*Plectrohyla psarosema** ?	2 June 2009	N17 11.324 W96 01.712	1648 m
*Plectrohyla psarosema** ?	2 June 2009	N17 11.324 W96 01.712	1648 m

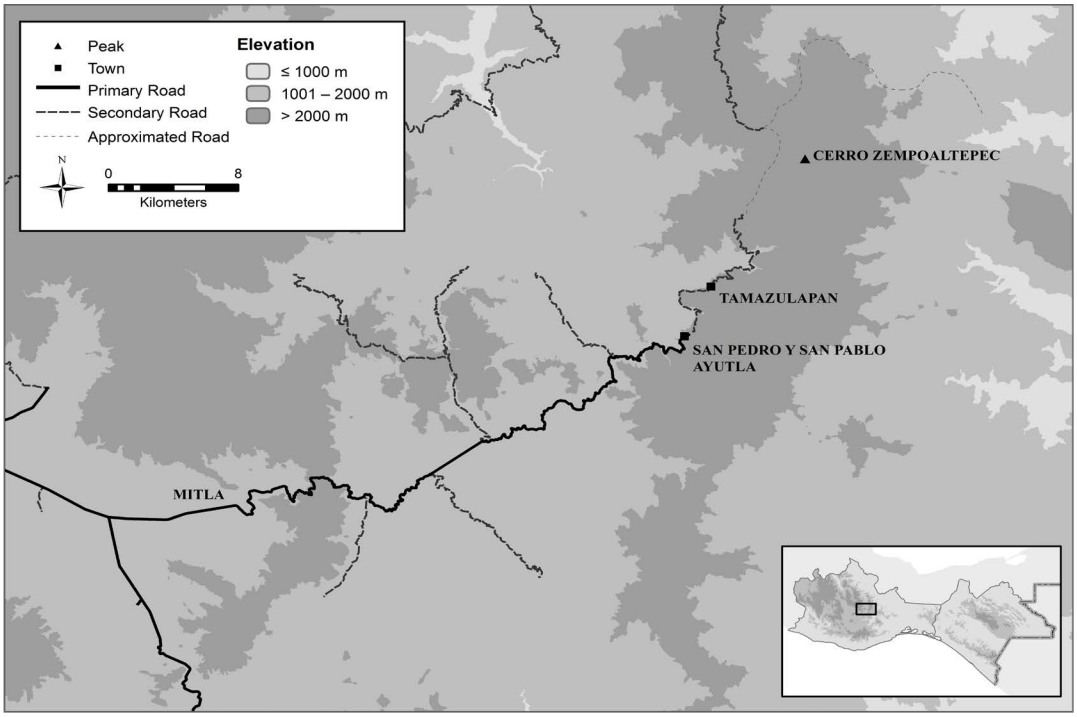
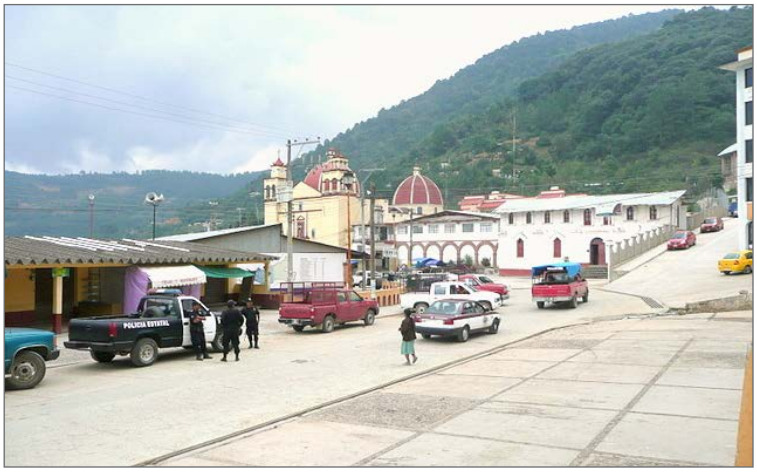


Fig. II-26. Map of the Ayutla AZE site.

Ayutla



Trigger Species	Last Year Observed
Salamander *Pseudoeurycea mystax,* EN B1ab(iii)	1999

Located: None.
Visits: 6–7 and 9–10 November 2008, 30 May 2009.
Conservation contact: None.

Delineation

This site encompasses the towns of Ayutla and Tamazulapan and their immediate surroundings. AZE (2010) lumped this site along with Totontepec in what they called Sierra Norte de Oaxaca II; however, we continue to follow AZE (2005), which treated Ayutla as distinct. For more about the delineation of this site see page 231, as well as Box IV-1 on page 241.

Background

Throughout the course of our project we thought *Pseudoeurycea mystax* was known only from a small area close to the town of Ayutla, thus the AZE site is named for the town. However, we have recently learned that the last place the species was recorded was in fact from the neighboring town of Tamazulapan (6.5 km by road and in another municipality). Because we learned of this fact in the late stages of review, we largely confine our discussion of the site to Ayutla. The official name of the town is San Pedro y San Pablo Ayutla, and it is situated at 2066 m in the Sierra Mixe of east–central Oaxaca. The town lies on the edge of the Oaxaca Valley as it rises into the mountains on its eastern side. It is 55 km from Mitla by paved road and this takes about an hour and a half to drive. The habitat of Ayutla is dry pine–oak forest with scattered madroña trees (Bogert 1967).

There are approximately 1,800 people living in the town center. The population is increasing because there is a high birth rate and little emigration. Ayutla is the

Fig. II-27. Authors meeting with Ayutla's mayor.

municipal seat and as such encompasses 108.45 km^2. The indigenous language is Mixe and many (perhaps most) adults speak it, but it is being lost in the area. Children in the primary school are taught only in Spanish, but one of the kindergartens is bilingual.

The main economic activity is agriculture, particularly of beans and corn. There is also a growing commercial sector. The town is not confronted by limited natural resources. For instance, it has an ample water supply. There have been no noticeable changes to the climate of Ayutla over the years (e.g., rainfall is the same in quantity and seasonality). Forest clearance, however, is unregulated and garbage disposal is less than ideal.

Conservation Measures

The people of Ayutla do not have an interest in conserving their natural resources. This sounds harsh, but we were told this by Alejandro Franco Conseco (Ayutla's mayor; Figure II-27) and independently by some of its citizens (Figure II-28). There is no management plan for timber in the municipality. Logging is uncontrolled and wood is mainly sold to other parts of Oaxaca. Although timber extraction is freely allowed, people are prohibited from unilaterally building houses in the forest. Hunting is prohibited, but still occurs. Mushrooms are collected from the forest, though only to a small degree.

Garbage disposal is a recognized problem in the municipality. Water is being contaminated as a result of metal cans and plastic bottles. Litter increased dramatically once Coca Cola and Pepsi products began to be sold here. The town dump is a wretched place that is periodically filled up, abandoned, and then opened anew at a different location. Tamazulapan, where *P. mystax* was last seen, has a recycling program, but nothing like this exists in Ayutla.

The lack of conservation in Ayutla is not due to a lack of conservation opportunities. Last year CONAFOR wanted to implement its nationwide Pro-Arbol program. Under this program CONAFOR offered to plant 950 trees per hectare and pay 946 pesos per hectare for the reforestation, but the townspeople rejected it. SEMARNAT also failed to implement another program. We do not know of any federal agencies or NGOs working for conservation in the area. There are different opinions as to why the town is reluctant to participate in conservation programs.

Fig. II-28. Heavily logged forests surrounding Ayutla.

Some say the people are ignorant of how the programs would benefit them and that they need to be educated/sold on the benefits first. Others say that there is a deep distrust of government because of past corruption. It is hard to say which is the more compelling reason, although the two are not mutually exclusive.

Species Account

Pseudoeurycea mystax, EN B1ab(iii)

The tale of *P. mystax* is an interesting one and it carries with it a moral: do not rely too heavily on a species' description. We did not find *P. mystax*, but thanks to David Wake and Gabriela Parra Olea we are able to report some information that could prove valuable to others who attempt to locate it.

Charles M. Bogert (1967) described *P. mystax* from two specimens that he and Godfrey C. Sluder found beneath rocks along the Río Alacrán, near Ayutla, in 1966. He also discussed another specimen taken from the same spot the following year. The description of *P. mystax* (Bogert 1967) led us to believe that it was a specialized riparian species:

> "The modifications in the feet and the distinctive pattern … are presumably adaptations to the somewhat specialized environment prevailing in the rocky ravines of the Sierra Madre del Sur in the vicinity of Ayutla." (pg.18–19)

> "No salamanders could be found on the steep slopes bordering the precipitous ravine where the type specimens were found." (pg.19–20)

> "the short, stout feet of *Pseudoeurycea mystax* are ill adapted for

Fig. II-29. Río Alacrán (and an ill-defined construction site), where it meets the bend in the road 1 km E of Ayutla (top left). Flow along the Río Alacrán; note the large amounts of "new" rock material (top right). Road from Tierra Blanca to Ayutla above the Río Alacrán, showing its loose fill and evidence of landslides (bottom left). Looking upstream along the river at the type locality for *Pseudoeurycea mystax;* note the overwhelming influence of landslides from the upper right (where the road cuts into the canyon wall) (bottom right).

> climbing. It may be inferred that these salamanders are terrestrial. Presumably they seek their prey on the floor of the ravine" (pg.20)
>
> "It is doubtful whether salamanders excavate burrows, but perhaps the modified feet of *Pseudoeurycea mystax* permit it to enlarge passages beneath rocks." (pg.20)

According to the Red List account, *P. mystax* is only known from "near Ayutla" (Parra-Olea & Wake 2008). We interpreted this as Bogert's Río Alacrán and we sought the species at this locality.

The exact location of the Río Alacrán is a bit uncertain. No one we met in Ayutla had heard of this river. There is a relatively major river 1 km E of Ayutla by road

Fig. II-30. A water truck on the road from Tierra Blanca to Ayutla. The truck is filling up with water from the large, cement storage tank on the left, which captures a spring that once flowed into the Río Alacrán below (to the right of the photo).

from the town cathedral. We assume this river to be Bogert's Río Alacrán as it coincides with his description of 0.9 km east–northeast of Ayutla. We learned later that this is the same river that David Wake and Ted Papenfuss presumed to be the Río Alacrán (D. Wake, pers. comm.). It is peculiar to us that not only was the name "Río Alacrán" unknown to everyone we met in Ayutla, but the river we assume is the Alacrán appeared not to have a name. We asked several inhabitants of Ayutla (the president of the commissariat and his staff, as well as several people who live along the river) its name. No one had a name for it, although it was known as "the river at the curve" (in the road).

Unfortunately, what we assumed to be the Río Alacrán has been spectacularly degraded (Figure II-29). Since Bogert's 1966 & 1967 visits, a road was constructed from Ayutla that heads into the canyon above the river on the western slope towards a small town called Tierra Blanca. Alejandro Franco Conseco said this road was built about 25–30 years ago, and it was present in 1981 (D. Wake, pers. comm.), but it was first paved five years ago. Two years ago a large storm washed the road out causing a landslide that covered the type locality of *P. mystax*. The road collapsed again last year and the canyon wall is so unstable that locals expect the road to be washed away with each summer's rainy season. A crew has spent the non-rainy

periods of the past two years carving deeper into the mountainside to repair the road. The rocks in the river are now coarse and unweathered. They are a far cry from the lichen- and moss-covered rocks that used to be present (Bogert 1967).

Further degradation to the river comes as a result of pollution and water extraction. Tierra Blanca, which is a few kilometers upstream from the type locality, would have been a tiny village in Bogert's day. It was probably tiny still in 1981, but five years ago the town received electricity from the Comisión Federal de Electricidad (CFE) and water services. It has since grown rapidly. Waste and debris from Tierra Blanca are evident downstream. Construction below the type locality by the main bridge over the river has led to increased sedimentation. Finally, a spring that used to feed into the type locality from caves in the canyon wall is now diverted into a holding tank, where the water awaits transport for human use (Figure II-30).

Despite the destruction of the riverine type locality, we searched it thoroughly. Not only did we fail to locate *P. mystax*, we did not find any salamanders near the river. We also searched every river in or near Ayutla without success. HerpNET (2014) lists five records of *P. mystax* by David Wake and Ted Papenfuss from 1981, which we believed to be the only time since 1967 that the species has been recorded. In terms of the Red List, we suspected that *P. mystax* should have been listed as CR (with the tag, Possibly Extinct) instead of EN. After all, to our knowledge the species had not been seen in nearly three decades, we could not find it, and the only known location for *P. mystax* was obliterated. However, what we learned from David Wake and Gabriela Parra Olea surprised us and makes the EN listing for *P. mystax* reasonable.

Wake and Papenfuss collected five specimens of *P. mystax* in 1981. From looking at the HerpNET records, we learned that four of these were from the Río Alacrán,[1] but one was not (MVZ 158816). This latter record was puzzling because its distance from Ayutla did not coincide with any river. We wrote David Wake about this and his reply was "why are you focused on a river? This is not a semiaquatic form at all, it is just that right near Ayutla everything is so cut over that it was only near the river that any remotely suitable habitat persists." In a subsequent email, Wake wrote that all five of their specimens came from roadside banks. One specimen came from the upper part of what he and Papenfuss presumed to be the Río Alacrán canyon. This individual was larger than the others and at first Wake assumed it to be *Pseudoeurycea cochranae* (EN), because Bogert (1967) mentioned that:

> "Another species, *Pseudoeurycea cochranae*, was taken approximately 15 kilometers to the west. This salamander may occur in wooded

[1] MVZ 158791–94.

> areas near the type locality, but it would be expected in the wooded mountain slopes rather than in the narrow ravine." (pg.20)

However, Wake and Papenfuss later determined that their specimen was *P. mystax*. In his email, Wake added that all of the *P. cochranae* specimens Bogert reported from the area might have been *P. mystax* (and *P. cochranae* is not currently mapped in Ayutla by the Red List; Parra-Olea *et al.* 2008). This is rather incredible. While describing *P. mystax* and how it differs from individuals of *P. cochranae* that were found at the same time, Bogert (1967) might have been discussing a single species.[2] Presumably, it is very difficult to tell *P. mystax* and *P. cochranae* apart.

We mention Wake's remark because it opens up a possibility that could be important. Currently the Red List maps one of the polygons for *P. cochranae* on Cerro Zempoaltepec (fairly near Ayutla though at much higher elevation). We only know of two records for it here (MVZ 163875–76).[3] John W. Wright collected the specimens in 1979 and it would be useful for someone to check these to see if perhaps they too are *P. mystax*, thus helping to clarify the distribution of the two species. In any case, if *P. cochranae* is not present in Ayutla, then *P. mystax* might be more common than we suspected.

For instance, if you talk to people in Ayutla about salamanders, you tend to get two reactions. Some of the people just stare at you blankly. Others seem to know exactly what you are talking about; these are more likely to be builders. They speak of two types of salamanders they regularly find beneath piles of sand or gravel used for construction. One is a dark salamander with bright red markings matching the description of *Pseudoeurycea boneti* (VU). The other is a dark salamander that we assumed was *P. cochranae*. If the latter is in fact *P. mystax*, then this species is not only found near Ayutla, but throughout the town as well.[4]

With the information from David Wake, we realize we relied too heavily on the description of *P. mystax* as possibly being tied to rivers. Even more surprising was

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[2] *P. cochranae* was originally described by Taylor (1943) and then briefly regarded as a synonym of *Pseudoeurycea sulcata* (Brame 1963)—which in turn is now considered a synonym of *P. cephalica* (Frost 2014). It was Bogert (1967) that removed *P. cochranae* from synonymy with *sulcata*. Furthermore, Bogert (1967) laid out the differences between *P. mystax* and *P. cochranae* in detail (see, for instance, his comparative figures 3,4,7,8).

[3] We consider Cerro Zempoaltepec to be part of the Totontepec AZE site (see page 147).

[4] When we told people we were looking for salamanders, one person took us to a house that was being renovated. He went through several piles of sand and gravel that workmen were using to mix concrete and said you often find the salamanders in the piles. We did not see any. We later asked a work crew by the side of a road that had similar piles whether they ever encountered salamanders and they described the same two species as being regular occurrences. This was before we thought it possible that these salamanders included *P. mystax*, therefore we did not seek out more construction sites.

learning from Gabriela Parra Olea that she along with Mario García París, Ted Papenfuss, and Roberto Bello collected two specimens of *P. mystax* on 9 August 1999 from just outside Tamazulapan (pers. comm.). She explained the find:

> "We stopped at the type locality and did not find salamanders, so we kept going past Tamazulapan and took a dirt road where we stopped and found one specimen under the bark of a good looking rotten log. We searched for a while longer but found nothing else. We drove about 600 m and made another stop. Ted found another *P. mystax* under a rock." (G. Parra Olea, 21 August 2014)

The two specimens were from N 17° 03.53 W 96° 02.04 (IBH23060) and N 17° 03.38 W 96° 01.22 (IBH22256), respectively.

Notes on IUCN Red List

Pseudoeurycea mystax is likely to be threatened by habitat destruction as deforestation is rampant within its range. More survey work, particularly of forest patches and wet roadside banks outside of Tamazulapan, along with further discussion with locals are priorities. As for placement on the Red List, EN seems appropriate to us, although one could make an argument for DD given that there are many unknowns concerning the species.

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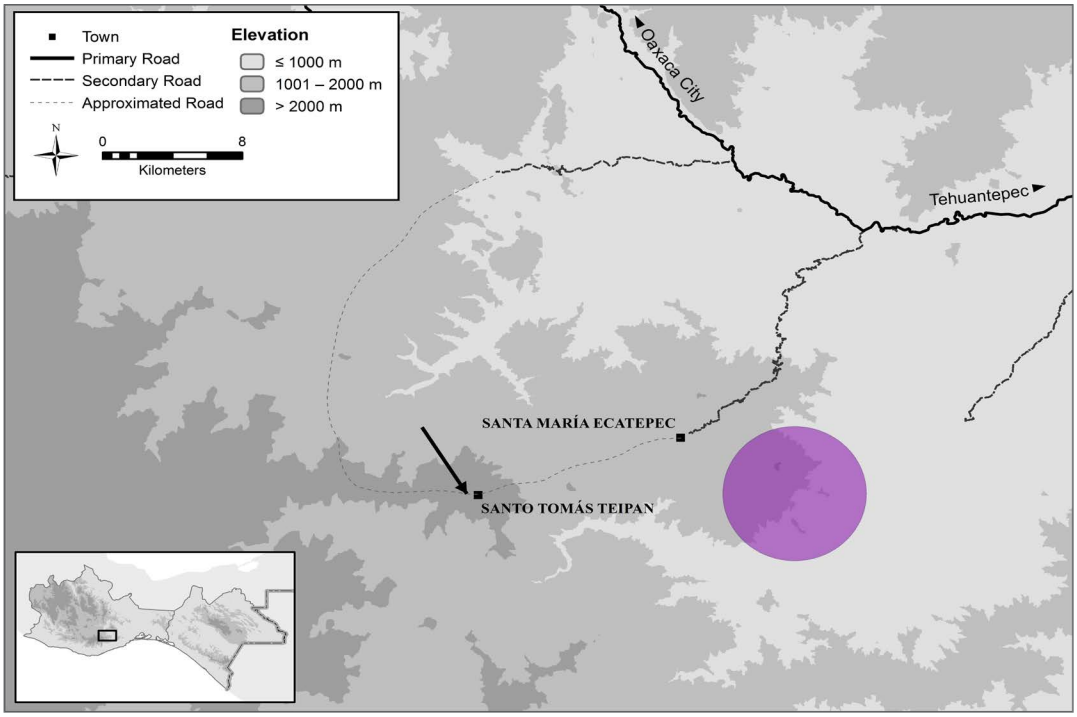

Fig. II-31. Map of the Santo Tomás Teipan AZE site. The purple polygon represents the range of *Thorius minutissimus* according to the IUCN Red List (Parra-Olea *et al.* 2008). The black arrow indicates the only known locality for the species, which is where we found it. We recommend that IUCN move the polygon slightly.

Santo Tomás Teipan

Trigger Species	**Last Year Observed**
Salamander *Thorius minutissimus,* CR B1ab(iii)	2009

Located: *Thorius minutissimus* – 1 individual.
Visit: 24–26 April 2009.
Conservation Contacts: NGOs: Ambientare, A.C. Government entities: CONAFOR.

Delineation

This site encompasses the cloud forest surrounding Santo Tomás Teipan.

Background

Taylor (1949) recorded the type locality for *Thorius minutissimus* as "Santo Tomas Tecpan," and this was the name given to the 2005 AZE site. We do not know if the name of the town has changed, or if Taylor made an error with its name, but it is currently known as Santo Tomás Teipan, and the locality has been listed as such at least since Goodwin (1969). The town sits at 2320 m at about the point where pine–oak forest transitions into predominately oak cloud forest (Figure II-32). It takes an hour and a half along a gravel road to drive here from the paved highway that runs from Tehuantepec to Oaxaca City. This would have taken much longer 10–15 years ago before major improvements to the gravel road were made.

The people of Santo Tomás Teipan (Municipality of Santa María Ecatepec) are of Chontal ethnicity, but few people, if any, still speak the Chontal language. Our local guide, Juan Mendoza Ortega (approximately 50 years old) says his parents spoke Chontal but he does not. One girl we spoke with (Daisy, approximately 14 years old) told us her parents had taught her Chontal words for tortilla, lime, and other foodstuffs; she also knew a few phrases in Chontal such as "I like tortillas." In 2004, the town's population was 183 adults. Currently, there are approximately 65

Fig. II-32. Looking down to the town of Santo Tomás Teipan (left). The production of cut flowers are the main livelihood of Santo Tomás Teipan (right).

comunares (people with written rights to the land, but this is not equivalent to the full population). There is a recent trend of men leaving the town to work elsewhere (to the "north," including the United States) and now there are more women in town than men.

The main livelihood in Santo Tomás Teipan is the production of cut flowers that are taken to Reforma and Tehuantepec to be sold, presumably for markets further afield (Figure II-32). They have been growing flowers commercially for about 10 years now that there is transportation for export. Flower cultivation is "traditional," but they have been taught techniques by outside groups as well (COINBIO, see below). No pesticides are used by the town.

Cultivated areas and livestock grazing grounds immediately surround the populated section of Santo Tomás Teipan (all the houses are together in one area). In the cultivated areas, they use the *rosa*, *tumba*, *quema* method of burning and planting, in which first everything is cut, then the fields are burned, and finally the fields are replanted after the first rain.

UNAM has a research project to study the traditional use of medicinal plants in the area. There are some medicinal herbs that are sold outside the town (these are taken from the forest, not cultivated), such as *tila*, which is used "for nerves." Resin is also harvested from pine trees and sold outside for a variety of uses. There are few pines in the forest where *T. minutissimus* is found (that forest is predominately oak), and those that do occur are not tapped. The resin project was instituted by CONAFOR. There is another project to raise and sell the meat of White-tailed Deer (*Odocoileus virginianus* LC).

Local lore has it that years ago (beyond immediate memory and at least more than 50 years in the past) a river flowed through the village. The river, however, disappeared after a man came from Tehuantepec and convinced the townspeople to cut down much of the surrounding forest and replace it with fruit trees. They have since gotten rid of the fruit trees and replanted some of the area with native tree species. After they planted the trees, the area where the river was became a bog, but this has been drying up and is a small area now.

Although the conservation efforts in Santo Tomás Teipan directly benefit *T. minutissimus*, the process has been undertaken by the community for other reasons—primarily for the water supply. There is an understanding that the natural forest is beneficial in terms of retaining water, and the community has a keen interest to understand more about what can be done to best manage resources for the future. At the time of our visit, water was available in town only every three days. Our visit was at the end of April, which is the driest time of the year. The rains start in May, but it does not truly become the rainy season until June. We were told that the dryness we saw was typical of that time of year (for at least the past 20 years).

Conservation Measures

The community of Santo Tomás Teipan has been working to conserve their remaining forest with the help of government agencies (mainly SEMARNAT, particularly CONAFOR) through projects such as COINBIO (Proyecto de Conservación de la Biodiversidad de Comunidades Indigenas de los Estados de Oaxaca, Michoacán y Guerrero) and PROCYMAF (Programa de Conservación y Manejo Forestal). Also, there is an NGO from Oaxaca City, Ambientare, A.C., which is working closely with the community on these projects. Ambientare is interested in developing ecotourism, with Military Macaws (*Ara militaris* VU) being of primary interest. These parrots are said to still be present in Santo Tomás Teipan despite having been eliminated from much of their former range. They are usually considered to have been extirpated or nearly extirpated from Oaxaca (e.g., see Howell & Webb 1995 and BirdLife International 2008).

There was a COINBIO workshop in 2005 that involved community mapping of soils, vegetation, management regimes, and water availability. In 2006, the community completed a resources conservation course with CONAFOR. The community has since set rules for resource management. Townspeople told us that for a while after CONAFOR first arrived the community was not committed to conservation, but in the two years prior to our visit they have become serious about enforcing conservation measures.

The town's land is divided into four zones (Odenamiento Territorial Comunitario

Fig. II-33. *Thorius minutissimus* (top panels). Juan Mendoza Ortega and Celevin Jimenez Ramirez helped us find *T. minutissimus* (lower left). The lower right photo shows the montane forest habitat of *T. minutissimus*.

2006):

Protection (433 ha in two pieces (one much larger – mesophytic/cloud forest; one tiny – dry forest), 13% of the total area): strict, no-use zone to be maintained in its "original state" with the one exception that the town can maintain the road banks that happen to cut through the forest.

Conservation (552 ha in two pieces (one larger – mesophytic/cloud forest; one smaller – dry forest), 17% of total): actions in this zone must "not affect the presence of trees or fauna." Uses include collecting non-wood forest products such as mushrooms, resin, and dead wood.

Use (2,252 ha in multiple pieces, 69% of total): in this zone specific uses must benefit families in the community; includes seasonally cultivated areas, grazing areas, the town itself, forested areas where non-wood forest product extraction is permitted, agave cultivation areas, hunting areas, wildlife management areas, grasslands, and firewood areas.

Restoration (50 ha – cloud forest, 2% of total): a zone to restore land to how it was before.

We were told that the area where *T. minutissimus* exists is within the conservation zone, but from the map we were shown it appeared that this was actually in the protected zone.

Timber products from all zones are only for use by the town (i.e., not for sale to the outside). There are penalties for breaking the rules. For example, in the no-use area, there are strict fines for taking/cutting downed trees—100 pesos for a first offence and 500 pesos for a second offense. The fine for cutting a standing tree is 1,000 pesos. The town will (or does currently) receive some federal money for implementation and enforcement. They will discuss the plan for a second *recursa* with CONAFOR, which could result in additional rules. We were told that every two months CONAFOR comes to check that the community is keeping up with the rules and that conservation targets are met. The community continues to work towards better understanding how to implement resource management for the long-term benefit of the town.

Species Account

Thorius minutissimus, CR B1ab(iii)

Thorius minutissimus is known from the town of Santo Tomás Teipan. The species was described by Edward Taylor in 1949 from a specimen collected in 1946 by Thomas MacDougall. The holotype and four paratypes are housed in AMNH and six more paratypes are in UIMNH (holotype: AMNH 52673, paratypes: AMNH 52674, 53930–53932[1] and UIMNH 3754–3759). Several additional specimens were collected by MacDougall in 1949, 1952, and 1955. There are other records for the species, but it is doubtful whether these actually represent *T. minutissimus*. Most notably, there are a number of records from Sola de la Vega, Oaxaca, but these belong to another species that has yet to be described (Rovito *et al.* 2013).

Thorius minutissimus was not recorded again until 2001 when Gabriela Parra Olea, Mario García-París, Tonia Tsieh, and James Hanken found two individuals along a roadside bank that cuts through intact montane forest approximately one kilometer west of town (J. Hanken, pers. comm.). Parra-Olea *et al.* (2008) noted that habitat protection was urgently needed because most of the intact, natural forest in the region surrounding the site had been altered or destroyed by logging, agriculture, and human settlement (this agrees with our observations of the region in general).

In April 2009, we visited the locality where the 2001 team had gone and found

[1] AMNH 53930 actually appears to be housed in KUH (as KUH 28080).

the area to be surprisingly unchanged from photos taken in 2001, especially for the forest along the road. We did not find *T. minutissimus* in the roadside bank, although our guide, Epifanio López Mendoza, managed to find an individual inside a moist, rotting log nearby (Figure II-33). As noted above, it was a very dry time of year. We also sought *T. minutissimus* in other parts of the forest above and below Santo Tomás Teipan without success. In fact, the only other amphibians we encountered were from the same locality as the salamander and consisted of two individuals of a *Craugastor* frog.

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Table II-4. Amphibians encountered at Santo Tomás Teipan, 24–26 April 2009. AZE species are marked with an asterisk (*).

Species	Date	Lat/Long	Elev
Craugastor sp.	24 April 2009	N16 15.075 W95 59.268	2461 m
Craugastor sp.	24 April 2009	N16 15.059 W95 59.280	2470 m
*Thorius minutissimus**	25 April 2009	N16 15.054 W95 59.272	2479 m

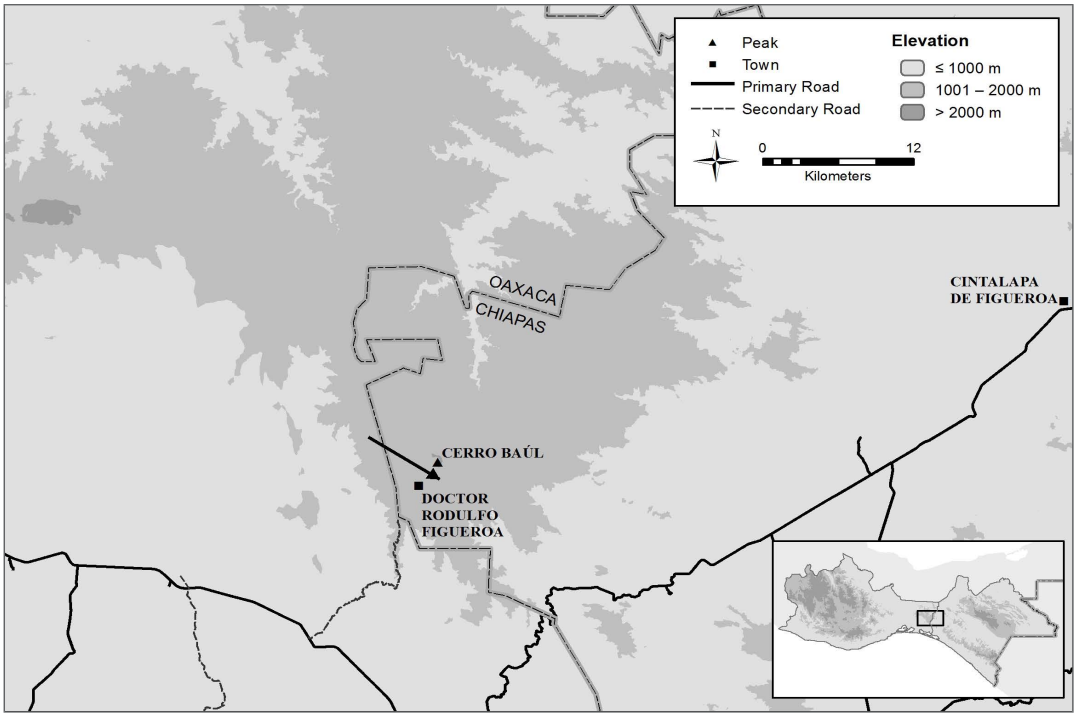

Fig. II-34. Map of the Chimalapas AZE site. The black arrow indicates where we located *Ixalotriton niger* and *I. parvus*.

Chimalapas

Trigger Species	Last Year Observed
Salamanders	
Ixalotriton niger, CR B1ab(iii)+2ab(iii)	2010
Ixalotriton parvus, CR B1ab(iii)+2ab(iii)	2009

Located: *I. niger* – 3 adults; 1 juvenile. *I. parvus* – 3 adults.
Visits: 5–7 March 2008, 14–17 May 2008, 18–19 June 2009.
Conservation Contacts: NGOs: Pronatura-Sur. Government entities: SEMARNAT.

Delineation

We retain the 2005 AZE delineation of this site, which encompassed the portions of Cerro Baúl that are within Ejido Doctor Rodulfo Figueroa (Figure II-35). This differs from AZE (2010) (see Figure IV-5, page 233).

Background – the Chimalapas Region (beyond just Cerro Baúl)

The Chimalapas region is distinct geographically. It lies east of the Isthmus of Tehuantepec (the lowland depression which serves both as the narrowest strip of land between the Atlantic and Pacific oceans in the country and as a major bio-geographical division, see Duellman 1960). The east side of the isthmus could be considered the edge of Mesoamerica, and Chimalapas displays this in a number of ways. It contains the most northerly populations of Resplendent Quetzal (*Pharomachrus mocinno* NT), which are common (Peterson *et al.* 2003). It is also likely to be the most northerly location for Horned Guan (*Oreophasis derbianus* EN) but this has not been confirmed, and there is a need for survey work for the species in Chimalapas (BirdLife International 2013). To the north, the border with Veracruz marks a drier lowland area on limestone substrates and further to the east are dry inland depressions separating (to some extent) Chimalapas from most of Chiapas.

Fig. II-35. Cerro Baúl (upper left). Landscape atop Cerro Baúl (upper right). The remaining cloud forest on Cerro Baúl contains many epiphytes (bottom).

Chimalapas is poorly known biologically and difficult to define in terms of what is manageable. It contains a diverse set of habitats, and often has a continuity of intact vegetation from lowland rainforest to upper montane forest that is rare in Mexico. Although Chimalapas comprises one of the largest roadless areas in Mexico, it contains just three small protected areas.[1] It is famous as a stronghold for megafauna

[1] The WDPA (IUCN & UNEP 2014) puts three protected areas within Chimalapas: Area Comunal Cerro Azul, El Bejucal y la Chichihua, and MVZ Benigno Hernandez Hidalgo. These are small areas in relation to Chimalapas as a whole, none is near Cerro Baúl, and none lists an IUCN protected area category (for a discussion of such designations see Dudley 2008). The first two are considered "certified" community areas. Until further information becomes available about these areas, it seems wise not to assume they provide real protection. Of course, certified communal areas could be fantastic protected areas; we just do not know enough at this point about these particular areas (see CONANP 2009 for a description of the program). At a quick glance, there also seems to be some question of accuracy. The type of protected area designation listed for MVZ Benigno Hernandez Hidalgo is as an urban park. This designation is comical given that the area is mapped within one of Mexico's most remote wilderness areas. Also, presumably Area Comunal Cerro Azul is supposed to overlap with Cerro Azul (the highest point in Chimalapas). If this is the case, the WDPA polygon for the communal area is misplaced (being approximately 30 km NW of Cerro Azul's peak). For more about the protected area see WWF (2007).

such as Jaguar (*Panthera onca* NT) and Baird's Tapir (*Tapirus bairdii* EN) (Naranjo 2009), and it contains high priority birds such as Harpy Eagle (*Harpia harpyja* NT), Ornate Hawk-eagle (*Spizaetus ornatus* NT), and Scarlet Macaw (*Ara macao* LC) (Peterson *et al.* 2003). Chimalapas was also designated as one of the Centres of Plant Diversity by WWF and IUCN (1994–1997).

Although most of the Chimalapas region lies within Oaxaca, there is little question that it is biogeographically more akin to Chiapas than to Oaxaca west of the Isthmus of Tehuantepec. The CEPF portion of the Mesoamerican hotspot stops at the isthmus for this reason. Binford (1989) lumped Chimalapas in with the coastal mountains of Chiapas listing the entire unit as "Sierra Madre de Chiapas," to which Peterson *et al.* (2003:229) took exception, calling it "a designation that would be worse than unacceptable to many of the region's inhabitants!" —presumably referring to the Oaxacan inhabitants.[2]

The Chimalapas region is part of the Selva Zoque, a landscape-level conservation and management unit that has been variously drawn, but that contains approximately 600,000 hectares with Chimalapas at its center. The indigenous Zoque people control most of the Chimalapas region despite being a minority of its population (about 35%) (Walker & Walker 2008). The region is administered as municipalities by two towns, Santa María Chimalapa and San Miguel Chimalapa. The towns were formally given full control of Chimalapas in 2004 (Walker & Walker 2008). Leading up to this, the Zoque witnessed the encroachment into Chimalapas by ranchers, loggers, and illegal drug growers and traffickers. In response they struck a deal with many of the non-Zoque villages around the perimeter whereby the towns would be deemed legitimate in exchange for helping to prevent further encroachment (by the towns themselves and newcomers). The towns would then be administered by the Zoque (Walker & Walker 2008). By many accounts this approach has worked to curb environmental degradation, but not all of the villages agreed to be incorporated. Of particular concern to the Zoque was encroachment from Chiapas, which was sponsored by the state government. There are bad feelings among the Oaxacan Zoque towards the de facto, yet unincorporated, villages of Chiapas. That said, not all of the unincorporated Chiapan villages continue to encroach or are poorly managed. Ejido Doctor Rodulfo Figueroa is a case in point. It contains much of Cerro Baúl, which is the small portion of the Chimalapas region that we consider to be the Chimalapas AZE site.

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[2] Peterson *et al.* (2003) are probably not alone in their protest of the name of Binford's (1989) biogeographical unit, but it is misguided. The Sierra Madre de Chiapas, including Chimalapas, is a designation that Binford (1989) neither created nor adopted exclusively. In fact, it often appears in biogeographical studies (e.g., for amphibians see Campbell 1999; Johnson *et al.* 2010). For other works using the Sierra Madre de Chiapas, either by that name or some other, see references in Morrone *et al.* (2002).

Fig. II-36. Photos taken at the base of Cerro Baúl. The school in Doctor Rodulfo Figueroa; note the map of Chiapas (left). Antonio Muñoz instructs a classroom about the importance of the mountain by showing them *Ixalotriton parvus*—a species found only here.

The Chimalapas AZE site

AZE (2005) listed Chimalapas as a site triggered by *Ixalotriton parvus*. *Ixalotriton parvus*, however, has only been recorded from Cerro Baúl at the SE edge of the mountain range. This mountain might also be the only current location for *Ixalotriton niger* (see below). Thus, an argument could be made that the AZE site should be called Cerro Baúl. We retain the earlier name because it is likely that other portions of the region will eventually be included as more becomes known.[3] Cerro Baúl is sometimes considered part of Oaxaca and sometimes as Chiapas—a result of lying on a disputed border with subsequent maps of the region alternating into which state to place it. In the Chimalapas region, Cerro Baúl has received the greatest amount of survey effort for vertebrates (Navarro-Sigüenza *et al.* 2008).

The ejido that contains the AZE area of Cerro Baúl is Doctor Rodulfo Figueroa (Figure II-36), which is located at 1295 m, and the top of Cerro Baúl is a little over 2000 m. It is 21 km by gravel road from Rizo de Oro. The ejido is administered by Cintalapa de Figueroa, Chiapas and its inhabitants adamantly consider themselves to be Chiapaneco. They refer to the rest of the mountain range as a separate entity and it is somewhat offensive to refer to either them, or Cerro Baúl, as being part of Chimalapas (or worse, Oaxaca).

Ejido Doctor Rodulfo Figueroa has approximately 250 inhabitants. Five years

[3] Other species in Chimalapas that could become additional AZE triggers should the site be expanded include: *Craugastor silvicola* (EN), *Exerodonta chimalapa* (EN), and *Anolis breedlovei* (EN) (these are discussed on pages 260, 246, and 247 respectively). Note the first two of these are treated as triggers by AZE (2010).

Fig. II-37. *Ixalotriton niger* from Cerro Baúl (top photos). We found *I. niger* in crevices of small caves (lower left), and in one instance we found a juvenile of this species in a fallen bromeliad (lower right).

ago the population was declining because families were leaving to another nearby village, but now the population is increasing again. The villagers are not of an indigenous ethnicity.

The ejido encompasses 2,100 hectares, but 1,400 hectares of this are in active contention with Oaxaca. The main economic activity is agriculture. Corn, beans, tomatoes, and shade coffee are all produced for domestic consumption. There appears to be no shortage of essential resources, including water, although some complain that the town lacks sufficient drainage and street lighting. Logging in the community for firewood and construction is permitted, as is hunting.

Conservation Measures

There is an agreed management plan for communal land. The plan, however, is not zoned—meaning there are not specific places designated for uses such as gathering firewood, conservation, or hunting.

The timing of the rainy seasons has remained the same over the years, but inhabitants note a change in climate. It is now warmer and there is less rainfall. About once a year someone's agricultural burn plot gets out of control, which results in a small fire. Other fires spill over from Oaxacan Chimalapas. None of these fires compare to the 1998 fire that burned the top of Cerro Baúl and surrounding mountains (Moore 1998; also see "Fire" on page 18) (Figure I-7 on page 22 and Figure II-35). The effects of that fire can be seen throughout the ejido.

Although numerous NGOs work in the Chimalapas region (Walker *et al.* 2007; WWF 2007), we know of only one doing conservation work in the AZE site as defined here. The NGO, Pronatura-Sur, works within Doctor Rodulfo Figueroa to survey for species and help with conservation planning, and they increasingly do so within the Oaxacan portion of the mountain range as well (see http://www.pronatura-sur.org/). A second entity, the government agency SEMARNAT, also works in the AZE site. This agency collaborates with the community on fire management and reforestation programs (see http://www.semarnat.gob.mx).

Species Accounts

Ixalotriton niger, CR B1ab(iii)+2ab(iii)

Ixalotriton niger was first collected by Jerry Johnson in January 1973 from El Pozo and it triggered the "Southwestern Chiapas" AZE site there (Ricketts *et al.* 2005). The importance of El Pozo is discussed in Box IV-2 (page 258) and again in relation to *Craugastor pozo* (page 255). As noted previously, *I. niger* is possibly no longer present at El Pozo. Despite many attempts to locate *I. niger*, we are unaware of anyone finding it there since Antonio Muñoz found six individuals in 2000. Continued deforestation, climate change, and the presence of *Bd* are all potential reasons for the sharp decline of *I. niger* at El Pozo. The species does exist on Cerro Baúl, however, and it should serve as an additional AZE trigger species for Chimalapas at least until it is found to have a viable population at El Pozo or another location.

In March and May 2008, we were with Antonio Muñoz when he located three adult salamanders from small caves on Cerro Baúl that appeared to be *I. niger*. Subsequent genetic analyses conducted by Gabriela Parra Olea confirmed these to be *I. niger* (A. Muñoz, pers. comm.) (Figure II-37). In 2010, Sean Rovito and Antonio Muñoz found nine individuals of this salamander in a single cave at Cerro Baúl (S. Rovito, pers. comm.).

The distance between El Pozo and Cerro Baúl is fairly large (95 km by air) and it is uncertain whether habitat between the two localities exists for *I. niger*. There has always been uncertainty about the preferred habitat of *I. niger*. It was found in El Pozo as a scansorial species on the trunks of large trees and sometimes on

Fig. II-38. *Ixalotriton parvus* from Cerro Baúl (top photos). Nora López León searching for *I. parvus* in a bromeliad near the top of the mountain (lower left), and a wider photo of its typical habitat (lower right).

limestone rocks. Thus, it was possibly an arboreal specialist living in the epiphytes of large trees, or alternatively a terrestrial, or even a cave-dwelling species. Wake and Johnson (1989) suspected that *I. niger* preferred the limestone crevices:

> "All individuals were collected at night. It is unknown if the salamanders spend daytime hours in the cracks and holes of the limestone substratum or if they descend at night from moist habitats in canopy epiphytes (*e.g.*, bromeliads). The former is supported by the number of individuals found on lower vegetation and on the limestone boulders. In addition, Dennis E. Breedlove (pers. comm.) has found no salamanders in epiphytes during field investigations of vegetation of the area." (pg.8)

Ixalotriton niger at Cerro Baúl certainly inhabits caves. That said, on our last trip to Cerro Baúl (June 2009), RCH found a juvenile *I. niger* in the axils of a bromeliad that was on the ground after having fallen from a tree (Figure II-37).

The Red List status of CR for *I. niger* (Parra-Olea *et al.* 2008a) is appropriate, although the account might benefit from some of the information we provide here. In particular, the Red List map for El Pozo should be corrected (it is not in the right location), and Cerro Baúl should be added as another site. Crevices are common on Cerro Baúl, especially at higher elevations where fire is a major threat to the species. One could easily imagine El Pozo being vulnerable to a large fire event as well.

Ixalotriton parvus, CR B1ab(iii)+2ab(iii)

This species is only known from Cerro Baúl. It was first collected by Ken Lucas, 8 September 1972. *Ixalotriton parvus* was thought to be possibly extinct because, despite efforts, it had not been located since the 1980s (Stuart *et al.* 2008). In 2007, a single individual was found (Ted Papenfuss, pers. comm. in Parra-Olea *et al.* 2008b).

Ixalotriton parvus inhabits montane bromeliads above 1600 m (Figure II-38). The forests on Cerro Baúl are cedar-dominated at this elevation. However, most of the forest was eliminated by the 1998 fire that cleared all the highest elevations, directly to the detriment of *I. parvus*. Lynch and Wake (1989) noted that the high elevation montane forests to the west of Cerro Baúl (in Chimalapas) had been poorly explored and might extend the range of the species—the forests to the west remain largely unexplored.

We found three individuals of *I. parvus* on three separate days between March 2008 and June 2009 (Figure II-38). All were in or near bromeliads and coincidentally all took about an hour to find. On two occasions we estimated our search effort. With five people, we found *I. parvus* after approximately 50 large bromeliads had been searched. Ten bromeliads searched per person per hour might sound low, but the terrain on top of Cerro Baúl is difficult to navigate (there is a large amount of woody debris, presumably fire remnants, a karstic substrate that is riddled with crevices, and dense undergrowth). We are confident that more individuals of *I. parvus* would be found on Cerro Baúl with increased search effort. However, we thought it unwise for us to survey further. More search effort would necessarily destroy habitat (i.e., bromeliads) for this CR species whose greatest threat is habitat destruction. We suggest that *I. parvus* be sought no more than once a year in general, and following any dramatic event affecting its habitat.

The designation of CR for this species (Parra-Olea *et al.* 2008b) is entirely appropriate. The forests on top of Cerro Baúl are being left to recover, but it will take many decades to return to pre-1998 form. The large amounts of woody debris and thick undergrowth also make another large fire likely within this time period. There is some deforestation at lower elevations that is moving upslope. Surveys for *I. parvus* in other high elevation areas in Chimalapas is a priority, but until it is found

elsewhere this species can only be thought of as leading a precarious existence. The Red List account states that protection and restoration of this species' habitat are essential (Parra-Olea *et al.* 2008b). This is certainly true, but as yet the mountain receives no formal protection and there is no restoration effort at high elevations.

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N.B. – We do not include a table of species we encountered for this site account.

III: ADDITIONAL AREAS/SITES VISITED

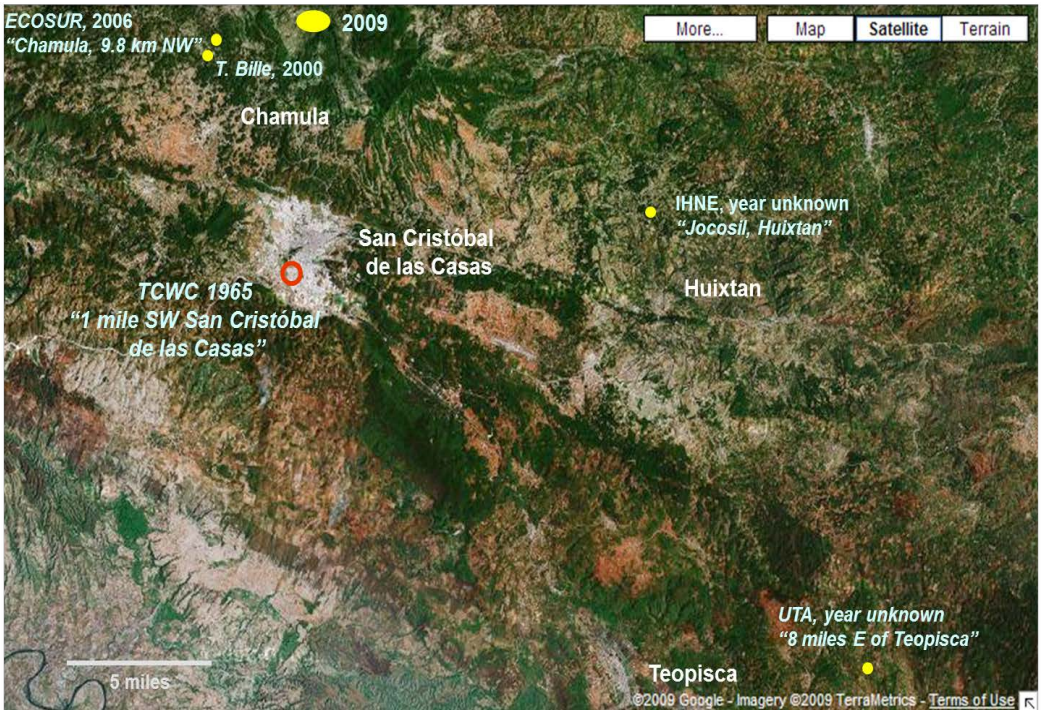

Fig. III-1. Satellite image from Google Maps of the region surrounding San Cristóbal de las Casas – showing locations where *Craugastor glaucus* has been found. The red circle marks the approximated type locality from within the Jovel Valley; other localities are marked in yellow. Note the vast amount of deforestation (non-green portions of the image).

San Cristóbal de las Casas

Fig. III-2. San Cristóbal de las Casas.

During the course of this project we were based in San Cristóbal de las Casas, a small city in the highlands of Chiapas. JFL and MWM arrived in January 2008 when the mountains around San Cristóbal[1] were considered an AZE site triggered by two amphibian species (AZE 2005). The current AZE map (AZE 2010) still has a dot on San Cristóbal marking an AZE site for Huitepec - Los Alcanfores. This site is triggered by San Cristóbal Shrew (*Sorex stizodon* CR), which was assessed by IUCN in detail for the first time by Cuarón *et al.* (2008) (for information pertaining to this species and site see page 244). Because we have a relatively large amount of material concerning the area around the city and its potential amphibian trigger species, including results of our fieldwork, we discuss it here in its own section.

To the best of our knowledge, the 2005 AZE site, "Cerros de San Cristóbal de las Casas," should not be listed as an amphibian AZE site. The site was originally triggered by two amphibians, *Plectrohyla pycnochila* and *Craugastor glaucus*. We spent substantially more time searching for these two species than any others in southern Mexico. It is quite possible that *P. pycnochila* no longer persists in the mountains surrounding San Cristóbal de las Casas, and *C. glaucus* is too wide ranging to be considered a trigger species. We did not locate *P. pycnochila*, but we were fortunate to encounter four individuals of *C. glaucus*.

Reserva Ecológica Huitepec was one of the places we searched repeatedly. The reserve is a private protected area managed and owned by Pronatura-Sur that lies 4–6 km outside of San Cristóbal de las Casas along the road to Chamula (for more about the reserve see page 244). We had seen checklists for the reserve that included both *P. pycnochila* and *C. glaucus*. We found no evidence that either species

[1] The city San Cristóbal de las Casas is often shortened to San Cristóbal. This was not always the case. Over the years San Cristóbal de las Casas has had several names and even more abbreviations (for a concise summary see Prado & Chandler 2009).

is currently present or has ever been found within it. In our judgment, the possibility of *P. pycnochila* being present in the reserve is particularly remote given that the frog is likely tied to streams and rivers of which Huitepec is lacking. There is a stream that runs along one side of the reserve, but it has been highly degraded. The stream's cover, where present, is low and brushy with all trees of stature having been removed. Livestock pollute the stream, and much, if not most, of its flow is diverted for human use by a series of small dams and a number of hoses. We mention this to dissuade the idea that *P. pycnochila* is present in Huitepec. Still, despite the serious problems with the adjacent stream, we believe its acquisition by Pronatura-Sur would be a wise long-term move. The stream is not beyond repair, and it could eventually provide a possible reintroduction site for another, more widespread CR frog, *Plectrohyla acanthodes* (see page 201).

Notes on the 2 former AZE trigger species

Craugastor glaucus, CR B1ab(iii)

The locations and dates of records for *C. glaucus* are essential to determine the status of the species. However, this seemingly simple information is remarkably difficult to obtain. *Craugastor glaucus* was described from individuals collected on 23 April 1965 by H. O. Persyn, 1.6 km SW of San Cristóbal de las Casas at 2100 m. Persyn collected four specimens on that date (TCWC 21460–63), but only three were used by Lynch (1967) to describe the species. No habitat information was reported in the description.

In old species descriptions there is often confusion about where mileage from a town begins. Sometimes distance from a town is marked from the town center (the zócalo and/or main cathedral) and at other times distance begins at a town's outskirts. The starting point is rarely specified. In this case, 1.6 km from San Cristóbal is very different if one starts from the center of town versus its edge. The distance and elevation, however, are consistent with specimens originating from the bottom of the Jovel Valley, where San Cristóbal lies.

The likely type locality for *C. glaucus* has undergone tremendous change since 1965. This change is best understood with a brief, historical aside. San Cristóbal was founded in 1528 by Diego de Mazariegos. The Jovel Valley is surrounded by mountains on all sides. The valley is described as being endorheic, but there were always a few natural "sinks" that accommodated some of the overflow during the rainy season. However, these were often blocked by debris or overwhelmed by heavy rains. Throughout the city's history floods were common and sometimes devastating. The SW section of the valley was relatively undeveloped—with marshes and lakes that grew when there were heavy rains (Velázquez-Velázquez and Schmitter-Soto 2004). García (2005) states that the first records of floods are from 1592. In 1785, Ignacio de Coronado, the mayor, requested an engineer to build an aqueduct to carry the

water away. This never happened and the problem continued. In 1921, the federal government, working with the state, ordered a plan to find a solution to the flooding (García 2005). The engineers, Francisco de P. Heredia and Juan Antonio Antúnez, developed a plan for a 4.3 km drainage tunnel through the valley wall, but tunnel construction would not begin until 1974 (García 2005). Thus, in 1965, the SW section of the valley still had few inhabitants due to the presence of marshes. With the security provided by the tunnel, San Cristóbal has expanded with great speed across the valley floor such that the likely type locality for *C. glaucus* is probably now within the city.

Other *C. glaucus* records exist, but are poorly documented. UTA lists a single individual from 8 miles E of Teopisca (UTA A-3570), but it is unclear whether or not the collector and date are known.[2] INHE has four records of the species from "Jocosil, Huixtan" (presumably equaling Jocosic in the municipality of Huixtan), a village east of San Cristóbal. These specimens used to belong to a collection that was housed in San Cristóbal and the dates associated with them were lost when the collection was acquired by INHE and moved to Tuxtla Gutiérrez (R. Luna Reyes, pers. comm.). Similarly, AMNH lists an undated specimen from Chiapas without locality details on HerpNET (2014) (AMNH 97527). Even dated specimens are not entirely satisfactory. On HerpNET (2014), ANSP lists a specimen collected by T. Uzzell on 26 January 1973 that is said to originate from Chiapas, but the record listing does not include further locality information so we exclude it from our map (ANSP 30383).[3] Ted Papenfuss and Antonio Muñoz found *C. glaucus* in August 2006 in a roadside bank near the town of Chamula. This specimen, however, appears to have been misplaced as neither Papenfuss (pers. comm.) nor Muñoz (pers. comm.) is sure where it is currently housed.

Thomas Bille (pers. comm.) also encountered *C. glaucus* in a roadside bank in Chamula, 9 July 2000 (16° 50.12' N, 92°41.43' W at 2220 m). Chamula is a town with jurisdiction over a wider municipality of the same name. Bille's *C. glaucus* was located in the municipality near the town. It was found beneath a stone in an open, highly disturbed forest. The only other amphibian found at the site was *Bolitoglossa hartwegi* (NT). Bille photographed the frog,[4] but did not collect it. It is tempting to say that *C. glaucus* prefers rocky microhabitats given that the only two mentions of habitat were rocky. If true, this might explain why the species has not been recorded from Huitepec Reserve. Huitepec is likely the most intact parcel of land within the

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[2] Mention of this record appeared in Canseco-Márquez and Smith (2004).

[3] In 2009, we were searching records on HerpNET and this specimen was listed then as coming from Tabasco. Chiapas is much more likely given that Tabasco is both low in elevation and far from San Cristóbal compared to other known records. It is unfortunate that more locality information did not appear as part of the correction.

[4] See pg.303 of Stuart *et al.* (2008), and fig. 379, pg.165 of Köhler (2011).

Fig. III-3. *Craugastor glaucus* from the municipality of Chamula.

known range of the species, but there are few rocky habitats inside it. We would not, however, put too much emphasis on rocky habitat. The people of Chamula tend to be suspicious of outsiders, particularly after dark when amphibians are most active. Thus, Chamula can be a difficult area in which to work. It is possible that rocky, roadside habitats simply receive a disproportionate amount of attention from herpetologists because they are more accessible than habitats on private land.

We found four individuals of *C. glaucus* in close proximity to each other next to a river on 6 April 2009 (Figure III-3). One individual was on a leaf close the ground. The others were either on the ground or the rocks along the river's bank. These are the only individuals we found despite extensive searching in the Jovel Valley and surrounding areas. Figure III-1 contains all mappable records for *C. glaucus* of which we are aware.

In our opinion, the range size of *C. glaucus* (particularly with the inclusion of the UTA record) is too large to be a manageable AZE site for a single species. The

Fig. III-4. *Plectrohyla pycnochila*. This specimen was collected by Dilford G. Carter 15 April 1965 from near San Cristóbal de las Casas (TCWC 21459). Photos courtesy of Toby Hibbitts.

decision is not a clear one and others could make an argument that the species should still trigger an AZE listing.

IUCN should reassess the conservation status of *C. glaucus* with the records we map. The EOO for *C. glaucus* is larger than 100 km^2, which means that the current B1 criterion threshold for CR range size is no longer met. The species, however, is now exceptionally rare. Antonio Muñoz, for instance, has only encountered it one time despite having spent many years living and working in San Cristóbal. Figure III-1 shows that there has been a great deal of fragmentation and habitat modification—most of which has occurred since the specimens described above were collected. In other words, while we urge a reassessment of the species we are not certain that its category would, or should, change.

Plectrohyla pycnochila, CR B1ab(iii)

Plectrohyla pycnochila is an enigmatic species. It was described from a single specimen that was collected in July 1954 by Byron Harrell. The location of this find was reported to be Los Tuxtlas near Coyame, Veracruz at about 1300 feet (Rabb

1959). Since that time there has been extensive herpetological work conducted in the isolated Los Tuxtlas range (see Vogt *et al.* 1997) without any sign of the species. Duellman (1970) raised doubts about the validity of the type locality and, upon questioning the collector, Duellman concluded that Harrell "is not certain that he obtained the type specimen of *pycnochila* in Los Tuxtlas. He intimated that the specimen may have originated in the highlands of central Chiapas" (pg.577).

The possibility that the first *P. pycnochila* specimen came from the highlands of central Chiapas is significant. Dilford G. Carter collected *P. pycnochila* from a cave north-northwest of San Cristóbal de las Casas in "pine-oak forest on a slope well above a small stream" (Duellman 1970:577) (Figure III-4). The locality is described as being at 2400 m and at either 5 kilometers (pg.577, Duellman 1970), 8 kilometers (pg.721, Duellman 1970), or 5 miles from town on 15 April 1965 (TCWC 21459). Because the specimen label appears to be 5 miles and this distance is roughly 8 kilometers, we used this distance as the most likely location near San Cristóbal to search for the species (though we searched in all directions and at a variety of distances).

Carter's central Chiapas locality is often thought to be the only record for which there is certain locality information. Duellman and Campbell (1992:14) state that "extensive field work in central Chiapas has revealed no additional specimens." More recently, Duellman wrote that "despite intensive work in central Chiapas, México, this species remains known from only one locality" (Duellman 2001:1053). The Red List also appears to acknowledge a single locality: "this species is known only from the Meseta Central of Chiapas, in northern San Cristobal de las Casas, Mexico, at 2,400m asl.," and "the range of this species does not include any protected areas, and protection of the forested areas surrounding San Cristobal de las Casas is needed" (Santos-Barrera & Canseco-Márquez 2004).

The interesting thing about the *P. pycnochila* Red List species account is that the mapped range is considerably north of San Cristóbal de las Casas (Santos-Barrera & Canseco-Márquez 2004). When we started our project, we viewed the IUCN mapped location as a mistake, but in May 2009 we found five additional records on HerpNET from Pueblo Nuevo Solistahuacán, Chiapas. These specimens were collected in January 1991 by Efraín Hernández García and are housed at UNAM (MZFC-Herp 7346-1 to 7350-1). Pueblo Nuevo Solistahuacán actually matches the location of the Red List map. We wrote Georgina Santos-Barrera about the apparent discrepancy between the newly appearing UNAM records on HerpNET and both the Red List text and Duellman's publications. Her response was that she too has collected the species, but only from Pueblo Nuevo Solistahuacán. Her specimens are apparently also held by UNAM, but did not appear on HerpNET (2009) and still do not (as of 26 May 2014). Santos-Barrera suggested that Antonio

Fig. III-5. *Plectrohyla acanthodes* from Molina de San Juan Chamula—just outside San Cristóbal de las Casas (upper left). Molina de San Juan Chamula. The trees mark the edge of a stream (upper right). Back side of the mountain that overlooks San Cristóbal. Photo taken from the old road to Tuxtla. On the left side of the mountain just out of view is Bochojbo Alto (lower left). Entrance to ZOOMAT's educational park near Bochojbo Alto on the old road to Tuxtla (lower right).

Muñoz might know more about these records. Antonio Muñoz is very knowledgeable about amphibians in Chiapas. He has also worked extensively in Pueblo Nuevo Solistahuacán and with the UNAM collection; however, Muñoz informed us that he was unaware of *P. pycnochila* from Pueblo Nuevo Solistahuacán. We think the species is more likely to be present at Pueblo Nuevo Solistahuacán than anywhere else such that it should be considered an AZE site (see page 234).

Notes on other species of interest

Plectrohyla acanthodes, CR B1ab(iii,v)

Plectrohyla acanthodes had been collected as far back as 1950 by William J. Riemer, "6 mi SE San Cristobal de las Casas," but at the time it was considered part of *P. guatemalensis*. Duellman and Campbell (1984) first noted that *P. guatemalensis* might contain three species (the nominate form and two others), and subsequently they described *P. acanthodes* (along with *P. teuchestes*) as part of a major revision of

the genus (Duellman & Campbell 1992). The holotype was collected by William E. Duellman and John Wellman on 5 August 1960 from a stream 6.2 km (by road) S of Rayón Mescalapa. Most of the specimens come from near this locality in the northern Meseta Central de Chiapas (equivalent to the Pueblo Nuevo AZE site discussed on page 234) and from the Sierra de los Cuchumatanes in western Guatemala. However, a few specimens are from just outside San Cristóbal de las Casas (Duellman & Campbell 1992; Duellman 2001), which is where we located the species. Our finds are important in terms of conservation because the San Cristóbal location has been ignored, the location could prove to be a stronghold for *P. acanthodes*, and we were able to show how a captive breeding program for the species could be started.

The Red List states that "recent searches in Guatemala have failed to find the species, and it seems that this population is declining. It is known now from only one locality in Chiapas, in a fragile ecosystem supporting only a few individuals" (Santos-Barrera *et al.* 2006). This statement could be used to support the listing of *P. acanthodes* as a trigger species for the Pueblo Nuevo AZE site. However, the Red List overlooks the fact that it is also known from San Cristóbal—a location it does not map.

We found *P. acanthodes* at two localities just outside San Cristóbal city limits within the municipalities of Chamula and Zinacantán (Figure III-5).[5] On 22 October 2008, we located a single adult *P. acanthodes* along Arroyo Chamula (at Molina de San Juan Chamula), the stream that runs from the town of Chamula to San Cristóbal. The frog was about five meters overhead in a conifer at 20:30 hr. We returned to the site on 3 November 2008 to search downstream (towards San Cristóbal) from where we found *P. acanthodes* before. At 20:50 hr. we found an adult at the stream's edge and we saw a few tadpoles. We made no attempt to capture the tadpoles; presumably they were *P. acanthodes*. We returned to this location on 7 May 2009 during daylight hours. We walked upstream towards the town of Chamula to find that the strip of forest where the frogs had been was only a few hundred meters long and it contained a considerable amount of garbage. Above the forest patch, the stream cuts through fields with no border such that habitat for the species here is severely limited.

The other place where we found *P. acanthodes* was a stream to the west of San Cristóbal. The most prominent feature of the San Cristóbal skyline is a mountain on its west side that is adorned with radio and television towers. Like all of the hills that surround the city, it is forested to look lush and green. ZOOMAT has a small

[5] In both cases, we urge the reader to be careful when visiting these areas—at one we were shot at and at the other we were warned that it was not safe after dark.

educational park (called Parque Educativo y Zoológico "San José Bocomtenelté") that was established in 1995 on the back side of this mountain (i.e., the far side from San Cristóbal), 10 km along the old highway to Tuxtla Gutiérrez. We met with staff of this facility and searched a stream within it without finding amphibians. Very close to San José Bocomtenelté, however, is a small, possibly seasonal, stream that comes down from the TV-towered mountain to cross the old highway.

We first saw tadpoles in this stream on 24 November 2008. We returned to the stream on 5 February 2009 to find that the stream had dried substantially. There were a number of pools that were usually connected by rivulets of water. It was clear that without rain these pools would disappear. Collectively, the pools contained hundreds of tadpoles, and we were uncertain as to their identity. We captured 18 of the tadpoles with the idea that we would rear them and confirm their identity. We were unable to locate frogs at this locality despite searching it on several occasions (we also searched another stream farther to the west without finding either tadpoles or frogs). We returned to the stream not long after we had taken our tadpoles and it was completely dry (Figure I-5, page 18). Given the time it took our tadpoles to develop, we assume that all the remaining tadpoles in the stream perished.

The portion of the stream in which we found *P. acanthodes* belongs to the village of Bochojbo Alto, which is part of the municipality of Zinacantán. Walking up from the road, the stream is forested to varying degrees on both sides. We were told that the land on the right hand side of the stream is privately owned, the upper part of which is being developed for housing, while the land on the left (to the west) belongs to Bochojbo Alto. The stream's water is used extensively, and according to the people we met access to the water is contentious. Along the stream there are several small dams, water holding tanks, and pipes that draw water at a number of points. We saw flower beds—some established along the streambed (flower cultivation is a major economic activity in Zinacantán). Heading upstream, the hillsides became noticeably more deforested a few kilometers above the road. At this point, the stream is very steep and the surrounding slopes consist almost entirely of crops down to the streambed itself. We were told that this is no longer Bochojbo Alto land, but belongs to the village of San Cristóbal (unrelated to the city of San Cristóbal; presumably the village is also part of Zinacantán).

JFL and MWM kept 11 of the tadpoles in two large aquaria in San Cristóbal (Figure III-6), while RCH cared for the remaining seven in Tuxtla Gutiérrez. Each aquarium was cleaned weekly, and water was dechlorinated and aerated (with a mechanical pump from a local pet store). We added gravel and leaves (from the Bochojbo Alto locality) to the bottom of the tanks, and fed the tadpoles pelleted rabbit feed and frozen lettuce. We soon noticed that the Tuxtla tadpoles developed rapidly compared to the San Cristóbal cohort. All seven of the Tuxtla tadpoles,

Fig. III-6. *Plectrohyla acanthodes* tadpoles and aquaria for metamorphs.

however, suddenly died for no apparent reason. One of the San Cristóbal tadpoles died as well, but the other ten grew into healthy *P. acanthodes* metamorphs.[6] There are many possible advantages to rearing tadpoles near the site of capture. Altitude, and the similarity in temperature it can provide, is perhaps the most important factor.

Rearing tadpoles is not simple, but it is much easier than caring for a population of adult treefrogs. We contacted Luis Carrillo of AfriCam Safari to pick up our metamorphs because of their remarkable captive breeding programs (see page 53). He arranged to have a government animal rescue permit granted for our care of the animals and then arrived by car from Puebla (Figure III-7). Luis and one of his staff drove our metamorphs back to Puebla, which is at roughly the same altitude as San Cristóbal. Luis later wrote us to say that the *P. acanthodes* frogs were all alive and well in their new setting. The Red List states that a necessary conservation

[6] The first nubs (bumps that are precursors to legs) appeared on 18 March 2009 and the first legs appeared on 6 April 2009.

Fig. III-7. *Plectrohyla acanthodes* metamorph (upper left). Luis Carrillo of AfriCam Safari inspects young *P. acanthodes* (upper right); MWM watches Luis remove additional metamorphs to be placed in containers for transport to Puebla (2 lower panels).

measure for *P. acanthodes* is the creation of a captive breeding program. Obviously our tadpoles are a very small start, but we think it would be possible to have a fully functioning captive breeding program for this species with individuals from these two localities on the edge of San Cristóbal. San José Bocomtenelté would be the ideal place to implement such a program.

Fig. III-8. New *Plectrohyla* species (6 April 2009).

New *Plectrohyla* species

Although we failed to locate the AZE trigger species, *Plectrohyla pycnochila*, near San Cristóbal (see "Deleted AZE 2005 Site: "Cerros de San Cristóbal de las Casas"" on page 253), we managed to find a new species of *Plectrohyla* while searching for it (Figure III-8). The genus ranges from central Mexico south to Honduras and El Salvador (and possibly Nicaragua).[7] Members of the genus *Plectrohyla* live along

[7] Brocchi (1877a) described *Plectrohyla guatemalensis* as the first species in the genus. The genus name, however, was not generally accepted until the 1940s (Hartweg 1941; Hartweg & Orton 1941). Even Brocchi stopped using the genus name within the same year he put it forward (see Brocchi 1877b). The *Hyla bistincta* group of treefrogs were thought to be a sister group to *Plectrohyla* (Duellman & Campbell 1992), but Faivovich *et al.*'s (2005) examination of Hylidae moved the *bistincta* group and a few other hylids into *Plectrohyla* (see footnote 5 on page 154). Before Faivovich *et al.* (2005), *Plectrohyla* was considered an example of a genus confined to the Nuclear Central American highlands of eastern Oaxaca through Guatemala to Honduras and El Salvador (Duellman & Campbell 1992; Campbell 1999). With the addition of the *bistincta* group, species such as *P. robertsorum, P. siopela,* and *P. pachyderma* extend the range of the genus into central Mexico and to the south Frost (2014) lists Nicaragua for an "undetermined larvae and subadult from Cerro Saslaya" (see Frost's account for *Plectrohyla*, though note while that account lists species from central Mexico it still refers to the northern extent of the genus as being southern Mexico). Presumably it is this same taxon from Cerro Saslaya that appears in a photograph by G. Köhler from the same location in Köhler (2011; fig. 622 pg.252).

Fig. III-9. Pointed prepollical process (upper panels). Rostral keel on the *Plectrohyla* we found (lower left).

cool montane streams and are at risk of extinction to a remarkable extent. IUCN considers 38 of the 42 known species to be threatened, with most of these being CR (Table III-1). There are few taxonomic groups of comparable size that are as highly threatened on the Red List.

Table III-1. Categories of the 42 species of Plectrohyla on the IUCN Red List. CR = Critically Endangered, EN = Endangered, VU = Vulnerable, LC = Least Concern, DD = Data Deficient. Threatened species are considered to be those that are CR, EN, or VU. Notice that three of the four non-threatened species are DD.

CR	EN	VU	LC	DD	Total
27	10	1	1	3	42

We captured seven adult individuals of a *Plectrohyla* species on 6 April 2009. Antonio Muñoz kept one of these for the Ecosur herpetological collection. We do not intend to formally describe the species here and we refrain from specifying where we found it; we would like to ensure that Antonio has enough time to describe the species.

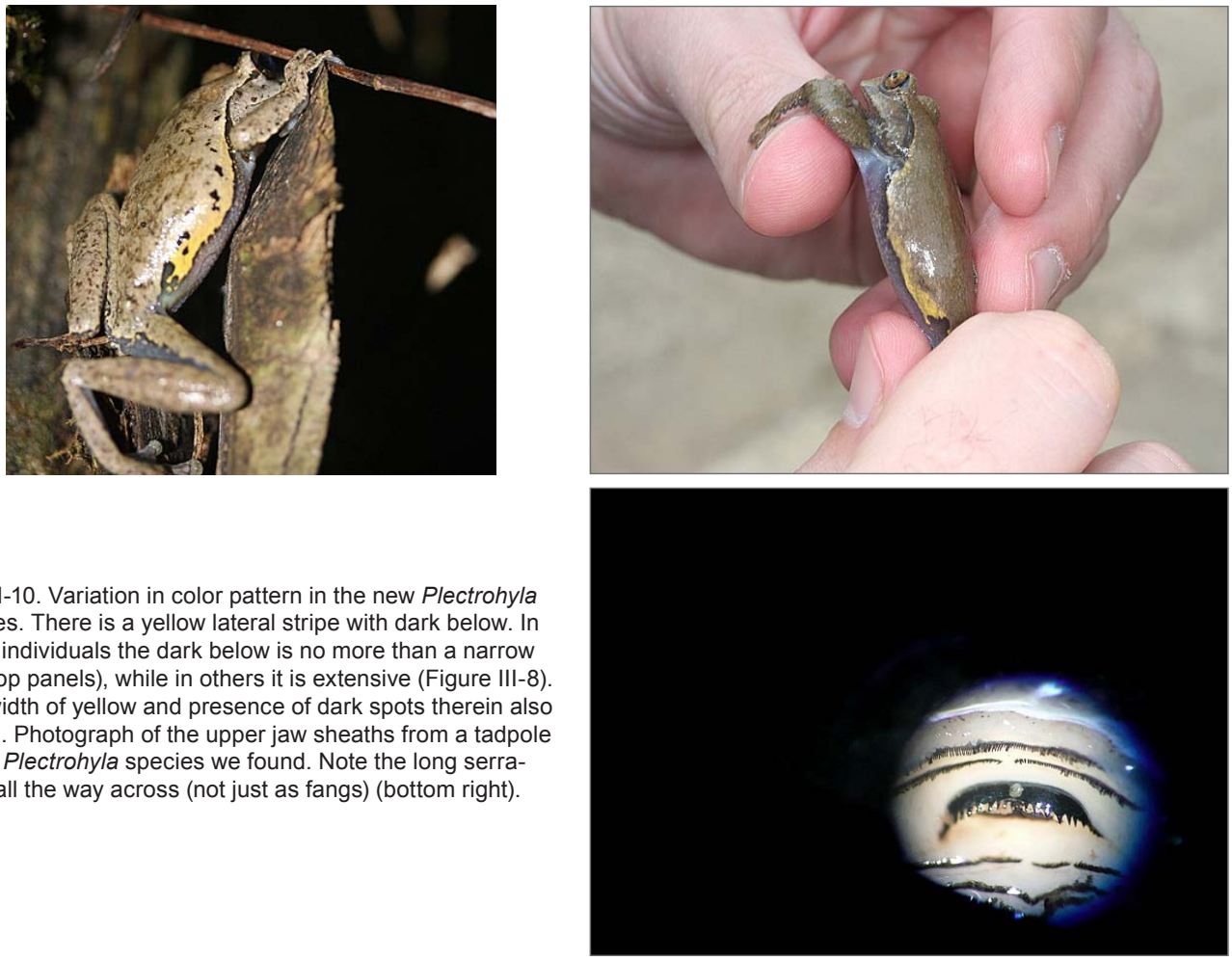

Fig. III-10. Variation in color pattern in the new *Plectrohyla* species. There is a yellow lateral stripe with dark below. In some individuals the dark below is no more than a narrow line (top panels), while in others it is extensive (Figure III-8). The width of yellow and presence of dark spots therein also varies. Photograph of the upper jaw sheaths from a tadpole of the *Plectrohyla* species we found. Note the long serrations all the way across (not just as fangs) (bottom right).

The frog we found is a member of the traditional *Plectrohyla* genus, and would either be most closely related to the *P. ixil* + *P. matudai* sister species or to the *P. quecchi* + *P. sagorum* sister species. The prepollical process is pointed, there is a vertical rostral keel, the snout is truncate (with a slight slope) in lateral view, and there is a yellow lateral stripe (sometimes containing dark spots) and bordered below by a dark line (Figures III-8–10). The coloring of the frog is most similar to *P. ixil* and at a first glance Antonio, who knows that species well, thought that was what we had found. However, on closer inspection the presence of a rostral keel (lacking for both *P. ixil* and *P. matudai*) eliminated that possibility, and, despite the coloration, make it more like *P. quecchi* and *P. sagorum*, which have rostral keels. The tadpoles we collected, however, are again most like *P. ixil* and *P. matudai* in that the upper jaw sheath contains enlarged fanglike serrations (not 1 or 2 on either side like *P. matudai*, or 3 or 4 like *P. ixil*—instead all are long enough to be considered fanglike) (Figure III-10). Determining its closest relative will likely be part of the formal description of the species.

In terms of conservation, the new *Plectrohyla* species does not appear to have a bright future. Its natural level of resistance to chytridiomycosis will probably be the leading determinant of whether this narrow-ranging species survives. At this point, it is anyone's guess.

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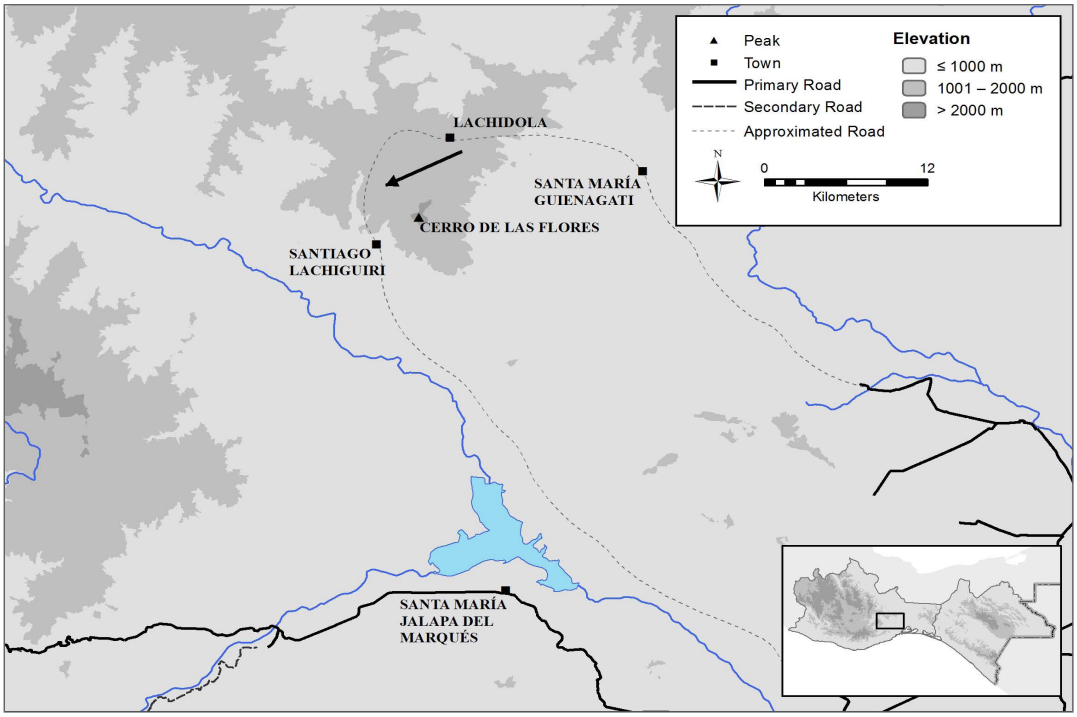
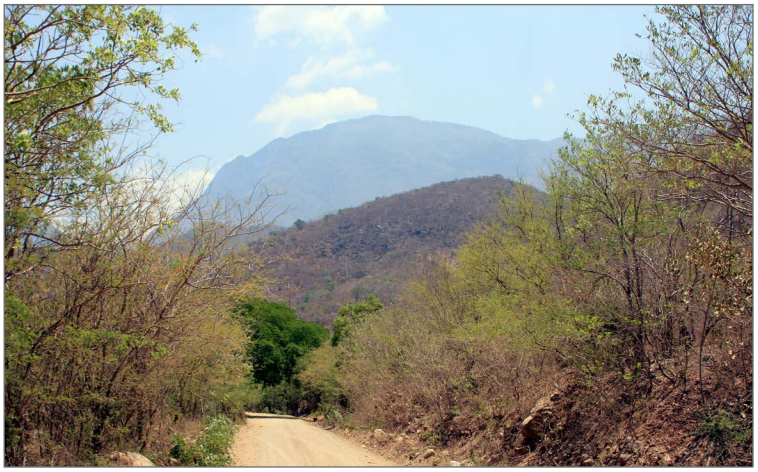


Fig. III-11. Map of Cerro de las Flores. The black arrow indicates where we found *Plectrohyla ephemera*.

Cerro de las Flores



This AZE site is triggered by *Plectrohyla ephemera*. When we began our project, Cerro de las Flores was not yet an AZE site because *P. ephemera* was described and placed onto the Red List just as the 2005 AZE list was released. We did not intend to visit the site as part of our project, but we managed a quick trip in April 2009 when returning to Chiapas from Santo Tomás Teipan. For this reason, we were unable to talk to many local people and this section is less detailed than our standard site accounts. However, we believe our short time at the site yielded findings that might be of interest to the reader. First and foremost, we located adult *P. ephemera*, which is currently listed as CR (PE) on the Red List (Mendelson 2006). We make the case that Cerro de las Flores should be secured, possibly as a national park.

Cerro de las Flores is a semi-isolated mountain at the southeastern edge of Oaxaca's Sierra Mixe (with the Isthmus of Tehuantepec just to the east) (Figure III-12). On 7 April 2003, E. N. Smith and L. Canseco-Márquez visited Cerro de las Flores and collected *P. ephemera*, a new species of treefrog closely related to *Plectrohyla calthula* (Meik *et al.* 2005). Smith and Canseco-Márquez found a single adult *P. ephemera* along a stream with several tadpoles. Three nearby streams also contained *P. ephemera* tadpoles. Meik *et al.* (2005) noted that nearly half of the tadpoles they found were missing mouthparts. The missing mouthparts led Meik *et al.* (2005:24) to name the species after the Greek word for short-lived, referring to the "ominous observation that chytridiomycosis may be present in the only known population of this unique species." Meik *et al.* (2005:25) believed the species to be at such imminent risk that two years after discovering the frog, they wrote "it is possible that the only known population of *H. ephemera* may already be extinct."

The Red List account for *P. ephemera* echoes Meik *et al.* (2005) when it states, "no information is currently available on the species' population status, but it is possible that it has undergone a serious decline due to chytridiomycosis, and the only known population might already be extinct" (Mendelson 2006). Cerro de las Flores is also rapidly being deforested. In fact, Mendelson (2006) viewed this as an even greater

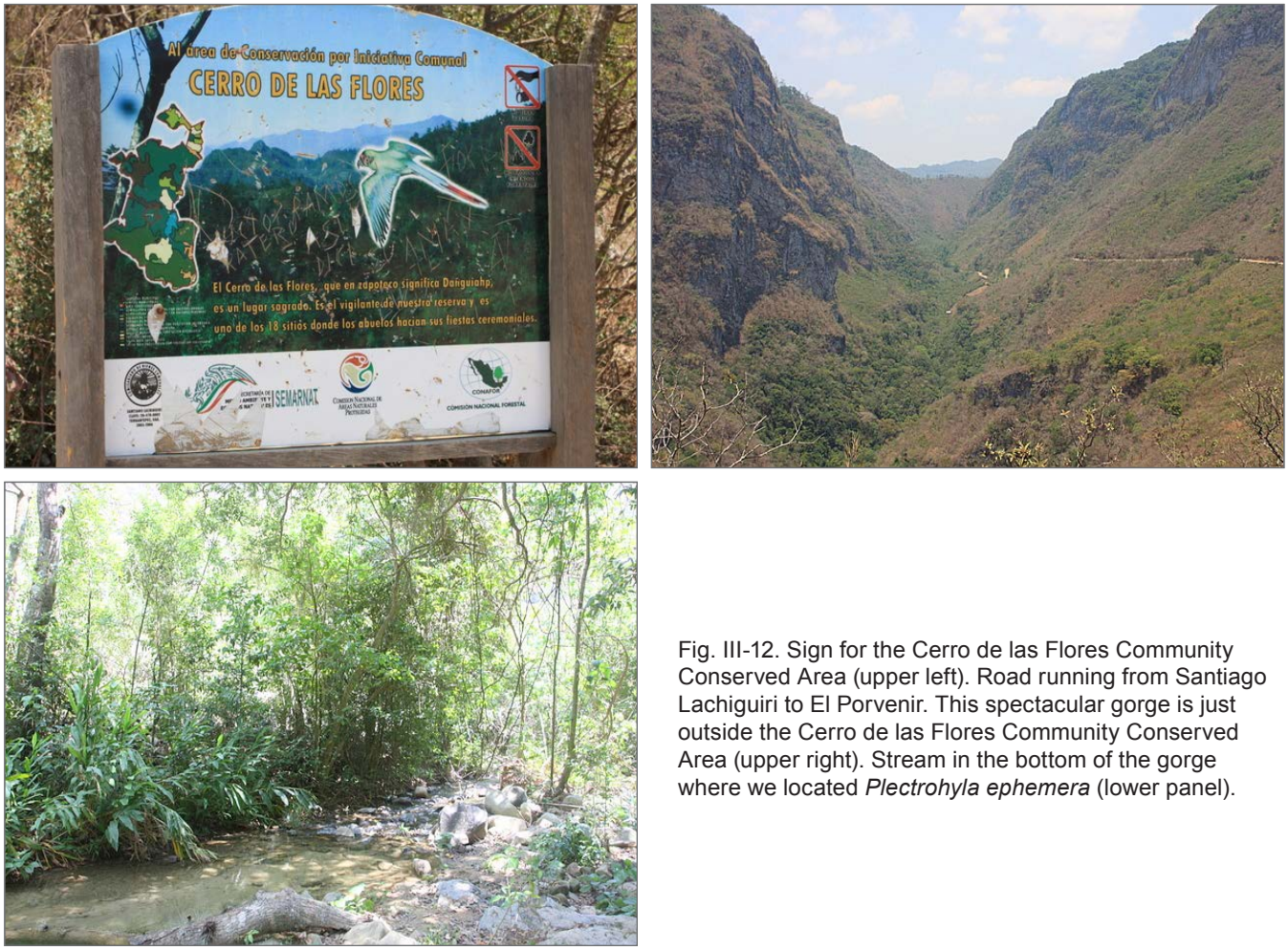


Fig. III-12. Sign for the Cerro de las Flores Community Conserved Area (upper left). Road running from Santiago Lachiguiri to El Porvenir. This spectacular gorge is just outside the Cerro de las Flores Community Conserved Area (upper right). Stream in the bottom of the gorge where we located *Plectrohyla ephemera* (lower panel).

threat to *P. ephemera* than *Bd* stating, "the primary threat to the species is habitat loss, and large expanses of forest are being cleared in this region." In our opinion, deforestation is a major threat to the species (see Figure III-13), but the primary threat remains chytridiomycosis, which presumably was the reason for *P. ephemera* being flagged as Possibly Extinct. Another possible threat to *P. ephemera* is the desiccation of its montane streams.

We retraced Smith and Canseco-Márquez's collecting localities for Cerro de Las Flores (as reported in Meik *et al.* 2005) on 26 April 2009 (6 years after their excursion). Wanton deforestation was evident at higher elevations along the road from Santa María Guienagati to Lachidola, which runs around northern portions of the mountain counter clockwise from the east to the west side. With so few people or crops, it seemed odd to have such extensive deforestation. We stopped at three of the four collecting localities, as well as at several other streambeds along the road. There was no water at any of these localities, which obviously prevented us from finding tadpoles (Figures III-13 & III-14). Meik *et al.* (2005:23) noted that the type locality for *P. ephemera*, where the only adult frog was collected, had "very little water flow."

Fig. III-13. Left panels: deforestation typical of the slopes near the type locality of *Plectrohyla ephemera*. The type locality has been degraded since *P. ephemera* was discovered in 2003. Meik *et al.* (2005) stated that "in general, the Sierra Mixe has suffered from greater habitat destruction than have the majority of other mountain ranges in central Oaxaca; however, many forested areas of the southeastern Sierra Mixe (including the type locality of *H. ephemera*) appeared to be relatively intact" (p.25). The type locality appears on the right hand side of the photo (right panel).

It is possible that there was still water at this stop when we visited, however, this was the one place we chose not to investigate because a group of people were right across the road from it and we did not want to attract undue attention to the locality. April should be the end of the dry season, so without the rains having begun our arrival probably coincided with the driest time of the year. The streams must have water at other times because we found a number of pipes that were designed to divert water. It would be interesting to know if either the deforestation on Cerro de las Flores or the water diversion has hastened the drying of streams here.

We were fortunate to locate *P. ephemera* on another part of the mountain (Figures III-14 & III-15). We are confident that the species not only exists, but thrives where we found it. There is some question about how long the species will be secure because of deforestation and chytridiomycosis. Cerro de las Flores contains a massive river gorge that runs north–south, draining the highest reaches of the

Fig. III-14. Dry streambed (one of many) near the type locality for *Plectrohyla ephemera*. Note the pipes for water diversion (upper left). A humid "waterfall" in moist forest that contains no water and is near the type locality for the species (upper right). New burn (within days) adjacent to the stream where we found *P. ephemera* (lower left). Lower right: two newly cleared fields (foreground and dark patch behind, which is the field from the photo to the left). The stream where we found *P. ephemera* lies in between.

mountain down past Santiago Lachiguiri and ultimately to the Benito Juárez Reservoir, where it serves as the water supply for Santa María Jalapa del Marqués, as well as for the city of Tehuantepec. The road from Santiago Lachiguiri to El Porvenir goes through the gorge and it is indeed an impressive site with large, cave-riddled cliffs on either side despite the fact that the stream itself is not very large. The valley floor is still almost entirely forested (Figure III-12). An elderly resident of El Porvenir told us this was because it remains shaded by the canyon walls for much of the day and it is too cold for cattle. However, while we were there new fields were being cleared and planted at El Porvenir (Figure III-14).

We found *P. ephemera* where the stream runs over the road just below El Porvenir (at 21:19 hr.) (Figures III-12 & III-15). We stopped our vehicle at the water's edge and immediately saw numerous tadpoles of more than one species. We then heard a deep, soft chuckle "tuk-tuk-tuk-tuk-tuk" given one time probably as an alarm,

Fig. III-15. Three photos of *Plectrohyla ephemera* (upper panels and lower left). Lower right: *Ptychohyla* sp., presumably *P. zophodes* as reported by Meik *et al.* (2005).

which proved to be *P. ephemera*. Tim Burkhardt (2006) wondered whether or not this species was capable of making sound. *Plectrohyla ephemera* lacks vocal slits, however, this is not necessarily an impediment to the production of sound. We heard the frogs making this noise again when handled. We captured four adult *P. ephemera* in total. At night they appeared as a rich, dark brown color—much darker cast than the following day when their skin became a cream color (we noticed this same color change in *P. calthula*). We encountered a small *Craugastor* sp. that eluded capture and a *Ptychohyla* sp., presumably *P. zophodes* as reported by Meik *et al.* (2005). The *Ptychohyla* sp. also changed color overnight, going from a pale yellow at the time of capture to a dark brown the next day (Figure III-15). We did not venture far from our vehicle, not knowing the ownership of the land. We have every reason to believe that *P. ephemera* and the other species of frogs would have been numerous, especially upstream.

The Mexican government should consider designating Cerro de las Flores, or large portions of it, as a national park. CONANP already has a small office in El Porvenir

that helps manage the Zona de Preservación Ecológica Cerro de las Flores. This protected area has been listed as a "Community Conserved Area" since 2003 on the *World Database of Protected Areas*, where it is mapped to include the highest elevations of the mountain down to El Porvenir (IUCN & UNEP 2014). Ideally, this area would be expanded to include the river gorge below El Porvenir and the overall designation of the reserve elevated to a higher level of status. The scenery of the area is worthy of national park status alone, and there is substantial biodiversity that could be lost without increased status. The possibility of additional microendemic amphibians and other taxa is high when neither the caves nor the higher elevations have been surveyed. The gorge and higher elevations remain largely intact, but this will not last without protection. For the moment, the land only flirts with the potential for other uses, thus it will never again be as easy to designate as a national park. At the same time, its value hydrologically, biologically, and scenically are all very high—far exceeding any short-term, marginal agricultural use. Furthermore, the new highway that will connect Oaxaca City to Tehuantepec nears completion and runs close to the base of Cerro de las Flores. When this road is finished the five-hour drive will become two hours, and increased traffic and tourism will follow. The added attraction for visitors of having a national park accessible from the highway would be to the benefit of locals, Oaxacans, and the nation.

Finally, we advocate for tighter controls to prevent the introduction of chytrid fungus to Cerro de las Flores. The stream where we found *P. ephemera* ran over the dirt road on which we were driving. While we were stopped, trucks passed through the water. The first step at preventing *Bd* would be to install a culvert for the stream to pass without coming into direct contact with vehicles. Second, the stream itself should be regulated so that people do not tromp through it (something we did not see, but that could occur with an increased number of visitors). Third, signs educating visitors about the dangers of spreading the fungus and ways to reduce the likelihood of this occurring should be posted at Cerro de las Flores. See page 277 for additional recommendations concerning chytridiomycosis.

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new species of *Hyla* (Anura: Hylidae) from Cerro Las Flores, Oaxaca, Mexico. *Zootaxa* 1046:17–27.

Mendelson, J., III. 2006. *Plectrohyla ephemera*. In: IUCN 2013. *IUCN Red List of Threatened Species*. Version 2013.2. <www.iucnredlist.org>. Downloaded on 11 May 2014.

IV: DELINEATION OF AZE SITES IN CHIAPAS AND OAXACA

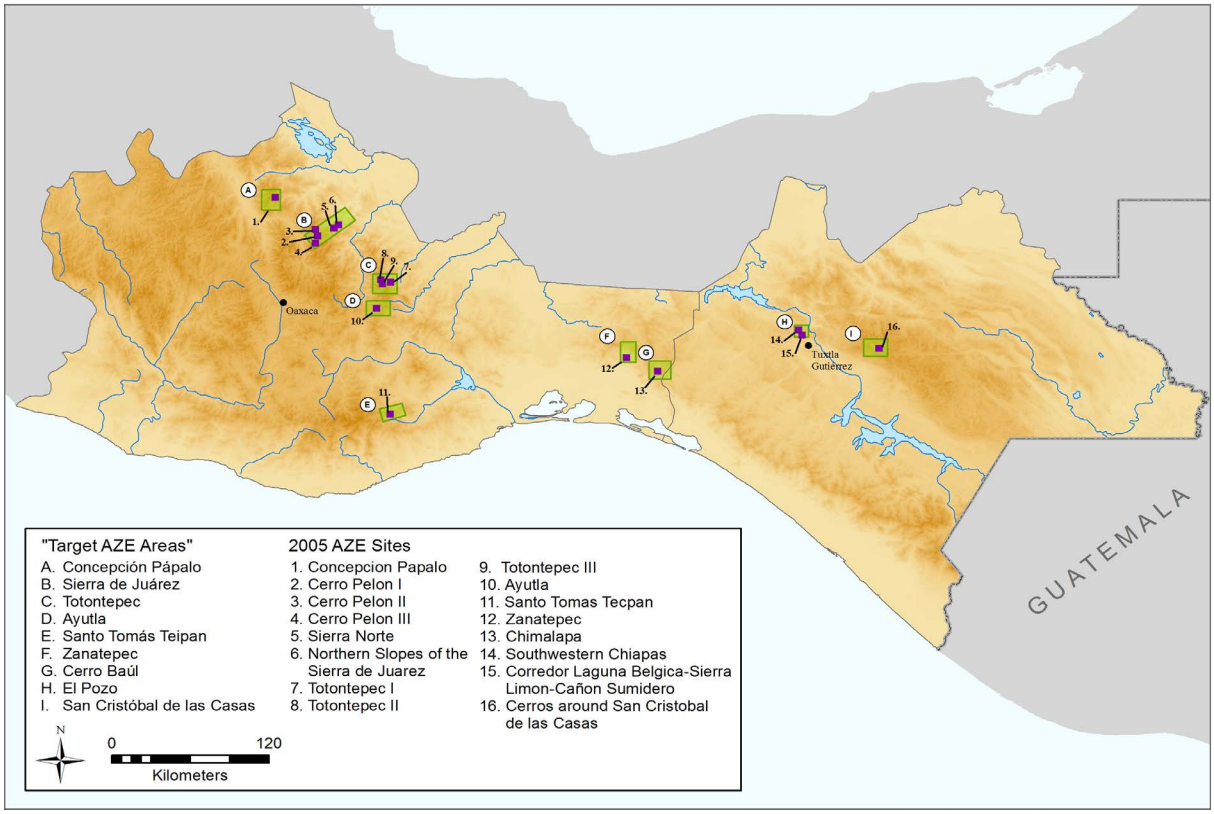

Fig. IV-1. Original (2005) amphibian AZE sites grouped into target areas that were the foci of our project.

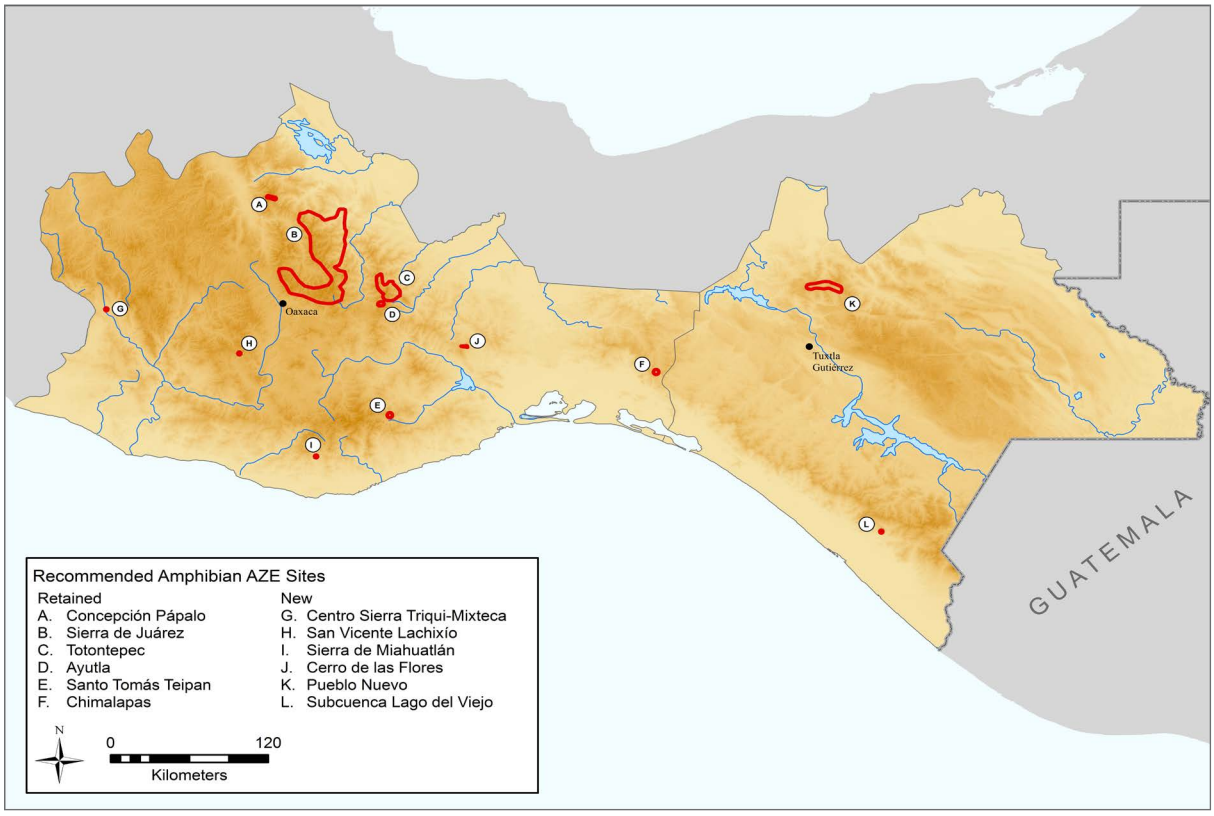

Fig. IV-2. Amphibian AZE sites recommended in this report. Note: other, non-amphibian AZE sites are described in this chapter, but do not appear on the map.

The Need for a New AZE List

When we began our project in January 2008, 16 amphibian AZE sites containing 22 amphibian trigger species were thought to exist in Chiapas and Oaxaca (Ricketts *et al.* 2005) (Table IV-1; Figure IV-1). Data about these sites and species were the object of our information gathering efforts. During the course of the project, it became apparent to us that the list of sites and species for the region needed a serious overhaul. In this section of the book, Part IV, we examine the reasons why a new AZE list was needed and we make recommendations pertaining to our region (Figure IV-2). We question some of the Red List categories for some of the species, but do not overrule the listings. Thus, if a species is EN on the Red List but we suspect it should be VU, we still keep it on our list of trigger species. However, we do make changes to our list of species based on our understanding of their distributions, which at times differs from information on the Red List. We discuss AZE sites and species for all taxa that have been assessed by the IUCN Red List, although we focus primarily on amphibians. Most of these recommendations were incorporated into the current AZE list (AZE 2010) along with input from a national AZE meeting that took place in Cozumel, June 2010, which RCH attended. We note the instances where we diverge from that list, many of which are due to the editors of AZE having to match sites to existing protected areas or management regimes (thus the differences have more to do with the boundaries of a site rather than the inclusion or exclusion of sites) (M. Foster, pers. comm.). In Part IV, we have the luxury of being less decisive than the global list in terms of what qualifies. We discuss the "maybes" and we are able to expand on our indecisiveness. Our recommendations to AZE regarding sites and species only included information prior October 2010. Since October 2010, we have opportunistically seen some things pertaining to the Mexican portion of the list that will likely cause future changes, but only in a few instances does this necessitate a minor change in our region.[1]

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[1] First, *Craugastor uno* (EN) should be removed from the AZE list. The species was thought to exist in possibly two locations (one in Guerrero and the other in Oaxaca). The taxonomic validity of the Oaxacan population was questioned by the authors of the Red List account, who stated: "the recent record from Oaxaca is probably in error and is currently under taxonomic revision" (Santos-Barrera & Canseco-Márquez 2004a). AZE (2010) discounted the Oaxacan record, thus making *C. uno* a trigger species in Guerrero (for the Sierra Madre del Sur site). Recently, genetic studies of the few known specimens from Oaxaca and Guerrero (more than the two sites mentioned because the authors collected additional specimens) indicated that they represent *C. uno* despite substantial variation in the appearance of individuals (Streicher *et al.* 2011a,b). Second, *Incilius cristatus* (CR) should be added as a trigger species. The Red List map includes seven or eight polygons for the species (Santos-Barrera *et al.* 2010); however, *I. cristatus* is still present at only two of these, which are within two kilometers of each other and represent a single location (Apulco and Barranca de Xocoyolo, Puebla). As mentioned previously, this species is now part of a captive breeding program (see page 53). Pertaining to our region, AZE (2010) listed *Habromys lepturus* (CR) as a trigger species for the Sierra de Juárez site, but this should have been Sierra Norte de Oaxaca II (analogous to our Totontepec site, see page 147). Similarly, *Microtus umbrosus* (EN) is likely confined to this site as well. Also, *Plectrohyla hazelae* (CR) qualifies as a trigger species following a re-evaluation of its distribution by Mendelson and

There are a number of reasons why AZE (2005) needed to be updated at the global scale and within our region. One reason was the increased taxonomic coverage by the IUCN Red List, although this has had little effect on the 2010 AZE list (and no effect on the Mexican portion of the list). AZE (2010), like its predecessor, only considered groups of species that had been comprehensively assessed by IUCN so that global comparisons could be made consistently. Thus, the 2005 AZE list included amphibians, birds, mammals, and conifers because every known species in these groups had been assessed (Ricketts *et al.* 2005). Some reptile groups meeting the AZE criteria were also included in 2005 because they had had all of their species assessed. Thus, species within order Testudines, order Crocodylia, and family Iguanidae that met the criteria made it onto the global list (Ricketts *et al.* 2005). In the years since the 2005 AZE list, the Red List has expanded taxonomically, yet the only group new to the global AZE list in 2010 was reef-building corals. The corals were comprehensively assessed by IUCN (see Carpenter *et al.* 2008), but no species was added to Mexico's portion of the AZE list as a result.

IUCN's reassessment of existing groups has led to changes on the AZE list. Most notably, mammals were revised to an unprecedented degree in 2008 with experts, for the first time producing detailed written accounts and range maps for each species (Schipper *et al.* 2008). Because of the mammal reassessment, several new AZE sites and species were added to our region. Also, while reptiles are still undergoing their first worldwide treatment, all of the reptiles of Mexico have been assessed, at least for the portions of their ranges within the country (NatureServe 2007). We discuss every reptile that qualifies or might qualify for AZE from our region, including species that are in groups other than turtles, crocodiles, and iguanas. Birds and conifers are the other two major taxonomic groups covered by AZE (2010), but, with the exception of *Juniperus standleyi* (EN), they are unlikely to have trigger species in our region.

Substantial changes to the AZE list in Chiapas and Oaxaca involve amphibians and are due to: taxonomic changes, increased understanding of species' distributions, updates to the conservation status of species on the Red List, and time to notice errors that were made in the initial rush to publish the 2005 AZE list. Changes to the Red List result from the re-evaluation of a species' status that corrects past errors, incorporates new data, and/or reflects real changes in the conservation status of the species. Because AZE sites are derived from species that are in categories EN and CR, changes to Red List status have the potential to both create and eliminate AZE sites. A number of updates to the amphibian Red List have occurred since 2004, which was the source for the 2005 AZE list. For example, in 2004 IUCN

Kabay (2009) (see discussion of Cerro San Felipe within "Delineation" starting on page 106). In addition, we treat both *Thorius adelos* (EN) and *Cryptotriton alvarezdeltoroi* (EN) as trigger species here (discussed further on pages 130 and 235, respectively).

listed several species as DD, such as *Thorius smithi*, that are now considered CR. Other species, such as *Plectrohyla cyanomma*, should have been included on the 2005 AZE list based on their Red List category in 2004, but were overlooked.

In recent years there have been many taxonomic changes to Mexican amphibians.[2] These can occur when species are added (by discovery or splitting), subtracted (by lumping or invalidation), or when names are modified in some way. Since the 2005 AZE list was produced, only one newly described species, *Plectrohyla ephemera*, needed to be added to the AZE list in our region (see page 213).[3] No species

[2] Changes specific to the list of Mexican herpetofauna were detailed in Flores-Villela and Canseco-Márquez (2004), which added species and noted name changes to the most often cited (previous) list by Flores-Villela (1993). However, there have been a number of changes to family and genus names following a massive re-evaluation of amphibian taxonomy by Frost *et al.* (2006). This work incorporated significant modifications to hylid frogs by Faivovich *et al.* (2005) and put forward a consistent taxonomic structure based on their own extensive analyses. Changes to the leptodactylid frogs come largely as a result of Crawford and Smith (2005), and the groupings of these species have been re-evaluated by Hedges *et al.* (2008). Such changes mean species lists for our region (e.g., Casas-Andreu *et al.* 2004) quickly become dated. Another recent list of Mexican herptiles was published in 2007 (i.e., Liner 2007a), and a separate work summarized its changes (Liner 2007b). At present, the most up to date Mexican lists can be drawn by querying two online databases (AmphibiaWeb 2014; Frost 2014). The two lists differ in terms of their taxonomic treatments and their species assignments, but both are constantly adding new information. For published, paper lists, the most complete work is probably an appendix to Wilson *et al.* (2013). However, we also like Liner and Casas-Andreu's (2008) list, which has the advantage of being written in both Spanish and English.

[3] The IUCN Red List makes an effort to quickly assess newly described amphibian species. In addition to *P. ephemera*, which is categorized as CR (PE), our region has seen the addition of several others, including: *Plectrohyla miahuatlanensis* (Meik *et al.* 2006), *Pseudoeurycea mixteca* (Canseco-Márquez & Gutiérrez-Mayén 2005), *Pseudoeurycea obesa* and *Pseudoeurycea papenfussi* (Parra-Olea *et al.* 2005a)—each was added to the Red List (categories DD, LC, DD, NT, respectively, thus not qualifying as AZE triggers).

We know of eight amphibian species recently described from Mexico that have yet to appear on the Red List. Only two of these are known to occur within our region, *Incilius aurarius* from Chiapas and Guatemala (Mendelson *et al.* 2012), which will probably qualify as an AZE trigger species once it is assessed by the Red List, and *Bolitoglossa chinanteca* from Oaxaca (Rovito *et al.* 2012) (see page 111). The other six are: *Charadrahyla tecuani* (Campbell *et al.* 2009), *Pseudoeurycea kuautli* (Campbell *et al.* 2013), and *Thorius hankeni* (Campbell *et al.* 2014) from Guerrero; *Pseudoeurycea cafetalera* from Veracruz (Parra-Olea *et al.* 2010); *Incilius mccoyi* from Chihuahua (Santos-Barrera & Villela 2011); and *Craugastor galacticorhinus* from Puebla (originally described as *Eleutherodactylus galacticorhinus* by Canseco-Márquez & Smith 2004). It is possible the Red List had reason to doubt the validity of these descriptions, but we are unaware of any such reasons. It is more likely that they have not been assessed because of financial constraints that the IUCN Red List works under, which limits the number of staff that can chase down the relevant information from experts.

In addition to newly described species, such as those we mention above, Wilson *et al.* (2013) highlight a number of taxa that they consider to be species requiring an assessment of conservation status, although they overstate the problem. These could be taxa that the Red List

required removal from the AZE list due to taxonomic changes; however, some were removed for other reasons. Furthermore, many of the species on the list have had their names modified since first appearing as an AZE trigger.

Published records of specimens are frozen in time, but our understanding of records is not. One of the consequences of this is that tracing a species on the current AZE list through the literature can be confusing. For example, Toal and Mendelson (1995:10) stated that "field work by J. A. Campbell and associates from UTA in the Sierra Mixe has resulted in the discovery of populations of *Hyla sabrina*, *H. crassa*, *H. celata*, and *H. arborescandens*." All four of the species have since had their genus changed to *Plectrohyla*, but greater changes have come from the re-assignment of most of these specimens. Neither *P. sabrina*, *P. celata*, nor *P. arborescandens* is now thought to have ever been present in the Sierra Mixe (although these species occur elsewhere—*P. sabrina* and *P. celata* are especially notable in that they are now considered endemic to the Sierra de Juárez AZE site, see page 105). Specimens from the Sierra Mixe that were first ascribed to *P. sabrina* have been re-assigned to either *P. psarosema* or *P. cyclada* (Campbell & Duellman 2000). *Plectrohyla celata* from the Sierra Mixe have all been reassigned to *P. cyclada* (Campbell & Duellman 2000), and *P. arborescandens* from the Sierra Mixe and from the Sierra de Juárez are also referred to as *P. cyclada* (Campbell & Duellman 2000). Interestingly, the

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assessors chose not to recognize as full species. For instance, Wilson *et al.* (2013) consider *Lithobates brownorum*, *Ambystoma mavortium*, *A. subsalsum*, and *Ensatina klauberi* as species that should be covered by the Red List, and each is mentioned in the account of the parent/sister species. In the case of *E. klauberi*, the debate of whether to consider the taxon as a species or not has been going on for years, and both Frost (2014) and AmphibiaWeb (2014) consider it a subspecies of *E. eschscholtzii* (LC). Another taxon listed by Wilson *et al.* (2013), *Pseudacris hypochondriaca*, was raised out of synonymy from *P. regilla* (LC) by Recuero *et al.* (2006) based on mtDNA, but nuDNA analysis by Barrow *et al.* (2014) appears to again support synonymy (Frost 2014). Wilson *et al.* (2013) also make three errors in their list of species that the Red List did not assess. Both *Spea bombifrons* and *S. multiplicata* were listed as LC, but were apparently overlooked by Wilson *et al.* (2013). *Eleutherodactylus albolabris* was also assessed, as CR, but appears as *E. dixoni* (a synonym) (Santos-Barrera & Canseco-Márquez 2004b).

Three other splits/resurrections are listed by Wilson *et al.* (2013) and are not mentioned within the Red List. Although none of these occurs within Oaxaca or Chiapas, each should be at least considered explicitly by the Red List (and probably assessed). *Acris blanchardi* was elevated to species (from *A. crepitans* LC) by Gamble *et al.* (2008) and a small portion of its range occurs in northern Mexico across from Texas, US. Streicher *et al.* (2012) resurrected *Gastrophryne mazatlanensis* Taylor (1943), which occurs along the NW coast of Mexico and Arizona, US, from *G. olivacea* and has yet to appear on the Red List. Similarly, *Craugastor saltator* does not appear on the Red List. It was described long ago (Taylor 1941), but was considered a synonym of *C. mexicanus* (LC) by Lynch (2000). Hedges *et al.* (2008) removed *C. saltator* from synonymy with *C. mexicanus* based on the findings of Crawford and Smith (2005), and we see no reason it should not be assessed. As an aside, much has been made of the resurrection of frog species described by Edward Taylor in the Philippines (Borrell *et al.* 2013); with both *G. mazatlanensis* and *C. saltator* being so recently resurrected from Mexico, it will be interesting to see if this becomes a trend here as well.

fourth species, *P. crassa*, is not mapped in the Sierra Mixe of Totontepec by either Duellman (2001) or the current IUCN Red List account (Santos-Barrera *et al.* 2006a), yet the former discusses it as present in Totontepec, and Campbell and Duellman (2000) list specimens of *P. crassa* from the Sierra Mixe (UTA A-5786, A-5842–43, A-5894). It is possible that we are unaware of a work that disputes the presence of *P. crassa* in the Sierra Mixe and the text of Duellman (2001) has not caught up with its own map (figure 404, pg.975, Duellman 2001), although the reverse is equally plausible. While the confusion surrounding the identity and correct names for the four species mentioned by Toal and Mendelson (1995) as being present the Sierra Mixe is more extreme than would be the case for most amphibians, it is not an isolated occurrence.

Knowledge of the distribution of amphibian species in Chiapas and Oaxaca is still far from perfect. More field work is required, but we suspect that consistent examination of existing specimens could also prove useful. For instance, specimens in the Smithsonian Institution collected in San Lucas Camotlán by linguist Walter Miller in the 1940s might shed light on the distributions of members of the *Plectrohyla bistincta* species group, *Ptychohyla leonhardschultzei* relative to *Ptychohyla zophodes*, *Megastomatohyla mixe*, and *Incilius spiculatus*. Mendelson (1997), for example, lists records for *I. spiculatus* from San Lucas Camotlán, but they are excluded from his map (figure 5, pg.278) and do not appear on the Red List map of the species (Santos-Barrera & Canseco-Márquez 2004c). This appears to be typical of the uncertainty herpetologists have concerning Miller's records, which is all the more reason these specimens, and others like them, should be re-examined.

Table IV-1. AZE (2005) amphibian sites and species in Chiapas and Oaxaca. Areas containing the original 16 amphibian AZE sites and their 22 trigger species in Oaxaca and Chiapas. These are the species we sought as part of our project. The names of species are from the Red List (see Figure 1 of Text Conventions and Appendices 1 & 3 for abbreviations and information pertaining to the Red List). NOM-059 is the Mexican threatened species list (P = En peligro de extinción; A = Amenazadas; Pr = Sujetas a protección especial). Note that some of these sites have additional amphibian trigger species since the 2005 list, which are not shown here (see Figure IV-3 for these).

2005 AZE Site	When we began our project			Current		
	2005 AZE Trigger Species	2004 Red List	NOM-059 2002	2010 AZE Trigger Species	2013.2 Red List	NOM-059 2010
1. Concepción Pápalo	*Thorius papaloae*	**EN**	*none*	*Thorius papaloae*	**EN**	*none*
2. Cerro Pelon I	*Thorius aureus*	**CR**	*none*	*Thorius aureus*	**CR**	*none*
3. Cerro Pelon II	*Plectrohyla calvicollina*	**CR**	*none*	*Plectrohyla calvicollina*	**CR**	*none*
4. Cerro Pelon III	*Plectrohyla celata*	**CR**	*none*	*Plectrohyla celata*	**CR**	*none*
5. Sierra Norte	*Thorius arboreus*	**EN**	*none*	*Thorius arboreus*	**EN**	*none*
	Plectrohyla sabrina	**EN**	**A**	*Plectrohyla sabrina*	**CR**	**A**
	Pseudoeurycea saltator	**EN**	**A**	*Pseudoeurycea saltator*	**CR**	**A**
	Megastomatohyla mixe	**CR**	**Pr**	*Megastomatohyla mixe*	**CR**	**Pr**
	Ecnomiohyla echinata	**CR**	**Pr**	*Ecnomiohyla echinata*	**CR**	**Pr**
	Craugastor polymniae	**CR**	**Pr**	*Craugastor polymniae*	**CR**	**Pr**
6. Northern slopes of Sierra de Juarez	*Lineatriton orchileucos*[1]	**EN**	*none*	*Pseudoeurycea orchileucos*	**EN**	*none*
7. Totontepec I	*Plectrohyla calthula*	**EN**	*none*	*Plectrohyla calthula*	**CR**	*none*
8. Totontepec II	*Plectrohyla psarosema*	**EN**	*none*	*Plectrohyla psarosema*	**CR**	*none*
9. Totontepec III	*Pseudoeurycea aquatica*	**CR**	*none*	*Pseudoeurycea aquatica*	**CR**	*none*
10. Ayutla	*Pseudoeurycea mystax*	**EN**	**A**	*Pseudoeurycea mystax*	**EN**	**A**
11. Santo Tomas Tecpan	*Thorius minutissimus*	**EN**	**Pr**	*Thorius minutissimus*	**CR**	**Pr**
12. Zanatepec, Isthmus of Tehuantepec	*Craugastor silvicola*	**EN**	**Pr**	*Craugastor silvicola*	**EN**	**Pr**
13. Chimalapas	*Ixalotriton parvus*	**CR**	**A**	*Pseudoeurycea parva*[2]	**CR**	**A**
14. Southwestern Chiapas	*Ixalotriton niger*	**CR**	**P**	*Pseudoeurycea nigra*[3]	**CR**	**P**
15. Corredor Laguna Belgica-Sierra Limon-Cañon Sumidero	*Craugastor pozo*	**CR**	*none*	*Craugastor pozo*	**CR**	*none*
16. Cerros de San Cristóbal de las Casas	*Plectrohyla pycnochila*	**CR**	**A**	*Plectrohyla pycnochila*	**CR**	**A**
	Craugastor glaucus	**CR**	**Pr**	*Craugastor glaucus*	**CR**	**Pr**

[1] Listed incorrectly by AZE (2005) as *Lineatriton orchimela*.

[2] This species is listed elsewhere within this book as *Ixalotriton parvus* (see Text Conventions page xix for a discussion of our departure from the Red List regarding this species' name).

[3] This species is listed elsewhere within this book as *Ixalotriton niger* (see Text Conventions page xix for a discussion of our departure from the Red List regarding this species' name).

Our Delineation of Amphibian AZE Sites

We used the 2005 AZE site list (Table IV-1; Figure IV-1) as our starting point. We proceeded to add, subtract, lump, and split sites (Figures IV-3 & IV-4). The greatest challenge to creating an AZE site list is deciding what is a geographically distinct, manageable unit—a requisite of AZE. In each case we present the rationale for our choice based on what we know about the relevant species and our interpretation of the delineation process. Where decisions were particularly difficult to make we note counter arguments that could prove more persuasive to the reader. We also discuss instances where site delineation was somewhat arbitrary—this can happen when one is drawing a line between two adjacent or nearly adjacent sites.

We put forward a list of 12 sites containing 34 amphibian species that qualify for AZE designation. In addition, there are two new sites that contain only non-amphibian species (Huitepec - Los Alcanfores and Mar Muerto-Pereyra) for a total of 10 non-amphibian AZE species when all sites for the region are included. Major differences from the 2005 AZE list include the lumping of five sites in the Sierra de Juárez into one and the combination of the three Totontepec sites. We recommend the addition of six entirely new amphibian sites (Pueblo Nuevo, Cerro de las Flores, San Vicente Lachixío, Subcuenca Lago del Viejo, Centro Sierra Triqui-Mixteca, and Sierra de Miahuatlán). We discuss eleven species (1 conifer, 4 amphibians, 3 reptiles, and 3 mammals) that might qualify as AZE triggers depending on questions of distribution and/or site definition (note: the three mammal species were listed as AZE 2010 triggers, including two sites for the *Tylomys* species alone). Finally, we favor the elimination of four sites from the 2005 list ("Cerros de San Cristóbal de las Casas," "Southwestern Chiapas," "Corredor Laguna Belgica-Sierra Limon-Cañon Sumidero," and "Zanatepec").

AZE Sites that were the Foci of Our Project

This section outlines six sites that were foci of our project and that qualify for AZE designation. Each of these AZE sites are discussed in greater detail within their respective site accounts such that we provide only a brief outline of their demarcation here. The first four sites (Concepción Pápalo, Sierra de Juárez, Totontepec, and Ayutla) along with Cerro de las Flores (see next section) are sites within the northern Oaxaca mountains. We discuss their boundaries relative to each other and the region's overall significance in terms of AZE species in Box IV-1 (page 241).

Each of the six units in this section qualified for the 2010 AZE list. However, two major differences exist between the sites we list here and AZE (2010). First, our Totontepec and Ayutla sites were combined by AZE (2010) into a single site they called Sierra Norte de Oaxaca II. We disagree with this combination and discuss the individual characteristics of these two sites in Box IV-1 and the relevant site

accounts (see Totontepec, page 147; Ayutla, page 163). Second, our boundaries for Sierra de Juárez, Totontepec, and Chimalapas yield smaller units than AZE (2010) (see Figure IV-5). The enlarged AZE (2010) polygon for Sierra de Juárez is particularly troublesome. Our Chimalapas site also differs greatly from AZE (2010). We favor the delineation of AZE (2005) as restricted to Cerro Baúl. However, the greater Chimalapas region is truly amazing and arguments for all of it being an AZE site are persuasive. See our discussion of *Craugastor silvicola* from "Zanatepec" (page 260), *Exerodonta chimalapa* (page 246), *Anolis breedlovei* (page 247), and the Chimalapas site account for more information (page 181).

AZE Site: Concepción Pápalo

AZE 2005 Site: "Concepción Pápalo"

See site account: page 91

Delineation

We retain the "Concepción Pápalo" site from AZE (2005). This site is triggered by the salamander, *Thorius papaloae* (EN).

AZE Site: Sierra de Juárez

2005 Sites: "Cerro Pelon I," "Cerro Pelon II," "Cerro Pelon III," "Sierra Norte," and "Northern slopes of the Sierra de Juarez"

See site account: page 105

Delineation

This site is centered on the mountains along Highway 175. The highway runs from Oaxaca City northeast to Tuxtepec and traverses Cerro San Felipe. Despite our inclusion of Cerro San Felipe and Ixtlán de Juárez, we know little about this part of the site or its species. For that reason, we confine our discussion of the site to the northern stretch of Highway 175. This portion of road, from Llano de las Flores and Cerro Machín in the south to Puerto Eligio in the north, encompasses five AZE sites from the original list ("Cerro Pelon I," "Cerro Pelon II," "Cerro Pelon III," "Sierra Norte," and "Northern slopes of the Sierra de Juarez"; Ricketts *et al.* 2005). Amphibian trigger species for the site include: *Craugastor polymniae* (CR), *Duellmanohyla ignicolor* (EN), *Ecnomiohyla echinata* (CR), *Megastomatohyla mixe* (CR), *Plectrohyla calvicollina* (CR), *Pl. celata* (CR), *Pl. cyanomma* (CR), *Pl. sabrina* (CR), *Pseudoeurycea orchileucos* (EN), *Ps. saltator* (CR), *Ps. smithi* (CR), *Thorius adelos* (EN), *T. arboreus* (EN), *T. aureus* (CR), *T. boreas* (EN), and *T. smithi* (CR). Cerro San Felipe adds an additional three amphibians: *Plectrohyla hazelae* (CR), *Pseudoeurycea unguidentis* (CR), and *Thorius pulmonaris* (EN). Sierra de Juárez also contains several mammalian trigger species (*Habromys chinanteco* CR, *H. ixtlani* CR, *Megadontomys cryophilus* EN, and *Microtus oaxacensis* EN).

AZE Site: Totontepec

AZE 2005 Sites: "Totontepec I," "Totontepec II," and "Totontepec III"

See site account: page 147

Delineation

This site includes the municipality of Totontepec and the wider valley in which it sits (including the municipality of Zacatepec). This is the only known place for the three amphibian trigger species: *Plectrohyla calthula* (CR), *Pl. psarosema* (CR), and *Pseudoeurycea aquatica* (CR). In addition, we include Cerro Zempoaltepec, which lies on the valley edge—adding two mammal trigger species to the site: Slender-tailed Deer Mouse (*Habromys lepturus* CR) and Zempoaltepec Vole (*Microtus umbrosus* EN).

AZE Site: Ayutla

AZE 2005 Site: "Ayutla"

See site account: page 163

Delineation

We retain the "Ayutla" site from AZE (2005). This site is triggered by the salamander, *Pseudoeurycea mystax* (EN).

AZE Site: Santo Tomás Teipan

AZE 2005 Site: "Santo Tomas Tecpan"

See site account: page 173

Delineation

We retain the "Santo Tomas Tecpan" site from AZE (2005), although we rename it Santo Tomás Teipan for reasons that we discuss in the site account. This site is triggered by the salamander, *Thorius minutissimus* (CR).

AZE Site: Chimalapas

AZE 2005 Site: "Chimalapas"

See site account: page 181

Delineation

We retain the "Chimalapas" site from AZE (2005). This site is triggered by two salamanders: *Ixalotriton parvus* (CR) and *I. niger* (CR).

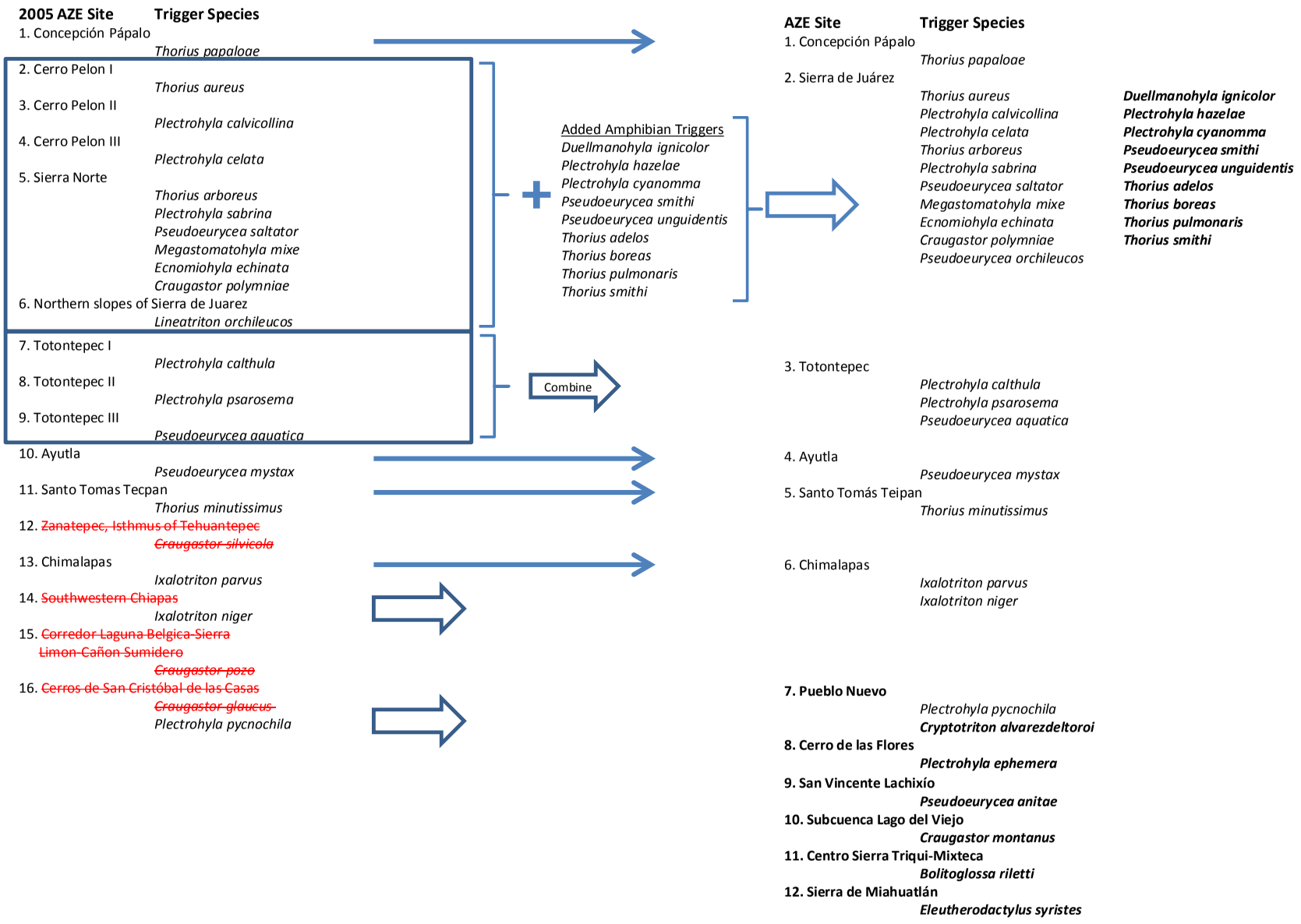

Fig. IV-3. Reconfiguration of AZE sites. Areas containing 16 amphibian AZE sites and their 22 trigger species in Oaxaca and Chiapas from 2005. The region now contains (conservatively) 12 amphibian AZE sites with 34 trigger species. New sites and species are shown in bold, deleted sites and species in red.

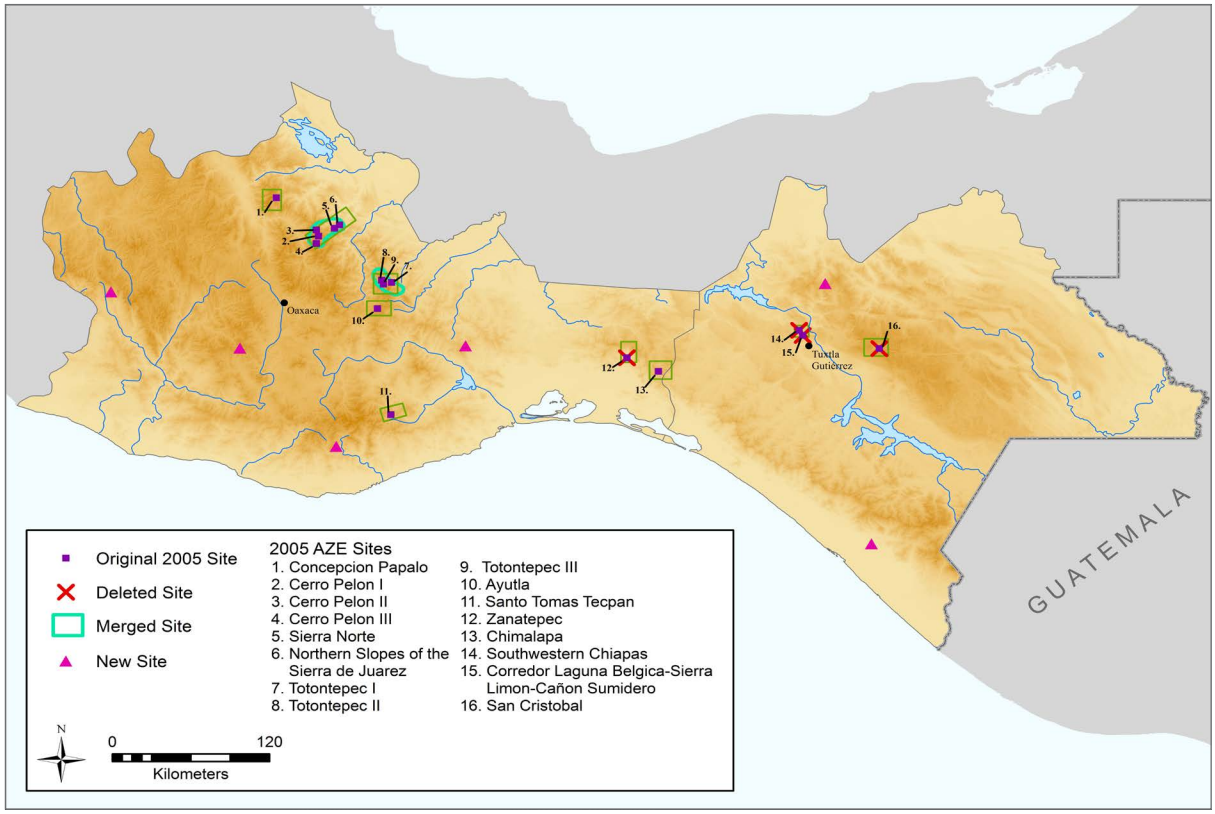

Fig. IV-4. 2005 AZE sites lumped and deleted—plus new amphibian sites added.

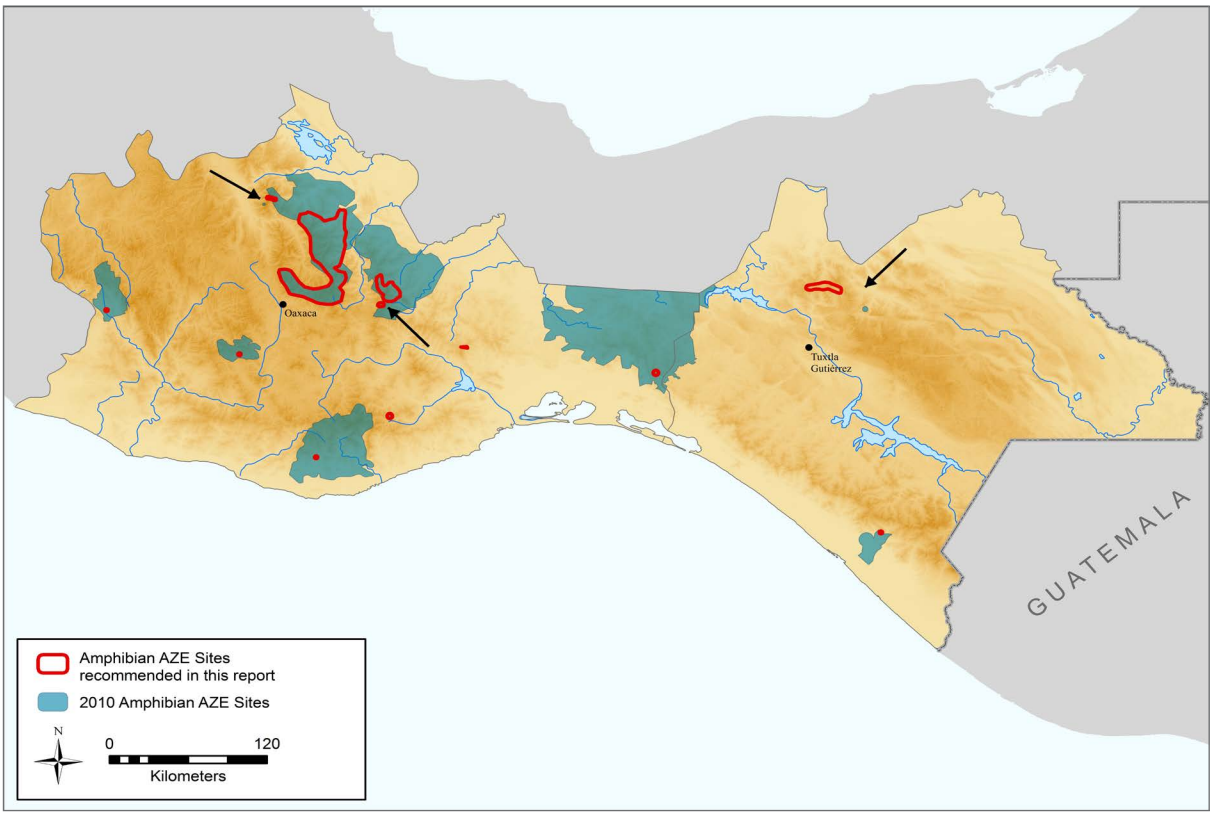

Fig. IV-5. 2010 amphibian AZE sites overlaid with our recommended sites. The black arrows point to discrepancies in placement (left arrow, Concepción Pápalo, and far right arrow, Pueblo Nuevo), and number of sites (middle arrow, Ayutla, which we recommend as a separate site). There are obvious differences among the sites in terms of size as well.

Additional AZE Amphibian Sites in Chiapas and Oaxaca

In this section we list amphibian AZE sites in Chiapas and Oaxaca that we recommended as additions to AZE (2005). Each of these sites is now recognized by AZE (2010). Most of these result from either omission errors in the previous lists or new IUCN Red List categories for the species that trigger them. Because these sites fell outside the remit of our grants we only found time to visit one of them, Cerro de las Flores.

AZE Site: Pueblo Nuevo

Description

The mountains in and around Pueblo Nuevo Solistahuacán are difficult to categorize in terms of biogeography as well as AZE. Jerry Johnson and his colleagues have treated the region as being on the boundary between the northern highlands and the central plateau of Chiapas that includes the "Cerros de San Cristóbal de las Casas" (e.g., Johnson *et al.* 1976; Johnson 1989). Johnson *et al.* (2010: 345) recently mapped these mountains as a stand-alone transition zone called the Central Plateau/Northern Highlands, which they describe as "where the Central Plateau and Northern Highlands (CP/NH) abut in north-central Chiapas, in the vicinity of Pueblo Nuevo Solistahuacán and Rayón".

We map the AZE site as being from just south of Jitotol along Highway 195 to Tapilula, plus the area west from Rayón to the local protected area of Tzama Cum Pümy, to include Tapalapa. At one time this area was covered by cloud forest that shared species with both the Central Plateau and Northern Highlands, but it also contained a number of unique species (Johnson *et al.* 2010). Today the cloud forest has been cut to the point that only a few fragments remain. One of the more famous collecting localities within this site is the Selva Negra, which is near Pueblo Nuevo along Highway 195 on the way to Pichucalco. Unfortunately, this particular patch of forest has been almost entirely deforested. Johnson *et al.* (2010) discuss another forest patch just above Pueblo Nuevo Solistahuacán called La Yerbabuena, which has been spared up to now as it is thought to be the water source for a local hospital. La Yerbabuena deserves special note because its bromeliads contain "at least one undescribed species of hylid frog" (Johnson *et al.* 2010: 345).

If we knew more about the species here, we might find that one or more of these fragments qualifies as an AZE site in its own right. Alternatively, with a better understanding of these forests we might contend that none of the fragments qualify either individually or when combined with others. We have chosen to treat the forest fragments collectively here because it is hard for us to justify denying AZE status to what once looks to have been a forest with a unique assortment of species simply because it has been chopped into smaller pieces that are now at greater risk

Fig. IV-6. Photograph of three rare *Craugastor* species. From left to right are: *C. taylori* (DD), *C. guerreroensis* (CR), and *C. yucatanensis* (NT). *C. taylori* has been recorded a single time (in 1960). The other two species exist outside our region. *C. guerreroensis* is interesting. It is listed as CR by IUCN; however, it is not flagged as Possibly Extinct (Appendix 2) despite the fact that the Red List account states "it appears to have gone into serious decline, and has not been recorded since 1984. Recent surveys to locate it have been unsuccessful, and it might now be extinct" (Santos-Barrera & Canseco-Márquez 2004). Photo courtesy of Eric Smith.

of disappearing. The site is triggered by *Plectrohyla pycnochila* (CR) (see page 199 for an account of this species) and *Cryptotriton alvarezdeltoroi* (EN), yet we discuss other potential trigger species as well.

Cryptotriton alvarezdeltoroi (EN) has been found just a handful of times. It is mapped with two polygons on the Red List (Parra-Olea *et al.* 2008a). One of these locations represents the type locality near Pueblo Nuevo. The other locality is likely for a specimen that was collected from a cave near Yajalón. There are no genetic data associated with this specimen and there is some doubt as to whether it is in fact *C. alvarezdeltoroi* (S. Rovito, pers. comm.). Furthermore, when Rovito visited the locality near Yajalón in 2007, he found it to be entirely deforested with no remaining suitable habitat. For these reasons, we do not consider this second locality to represent a viable population. There is, however, a recently collected specimen from 1.7 km N of the highway from Tapalapa to Pantepec on the road to Maxono (17.20367 N, -93.10505 W, 1836 m elevation) (S. Rovito, pers. comm.), which would fall within the Pueblo Nuevo site as we have drawn it here. *Cryptotriton*

alvarezdeltoroi probably warrants a CR listing.

The Pueblo Nuevo site would also include *Craugastor taylori* (DD) as a trigger were this species listed as either EN or CR in the future (Figure IV-6). We do not mention this idly; we believe the listing of *C. taylori* should be revisited and changed to CR. The species is known from a single specimen collected by William Duellman in the summer of 1960 near Pueblo Nuevo. In the description of the species, Lynch (1966:78) stated that the little-known frog "probably occurs over much of the Chiapan highlands." Lack of knowledge and geographical optimism about the species' distribution is repeated in the current Red List account that says although *C. taylori* is only known from the type locality "it might occur more widely" and "there is no recent information regarding its population status, presumably due to a lack of herpetological work within its range" (Santos-Barrera 2004a).

It is true that the region has not had a tremendous amount of herpetological work. *Craugastor taylori*, however, is certainly not widespread in the Chiapan highlands. Unlike other amphibian species from the Pueblo Nuevo region, it alone remains known from a single specimen. The fact that none of the excellent researchers that have collected in Pueblo Nuevo have been able to find this species in the past half century convinces us that it is extremely rare. Other *Craugastor* species in Chiapas are thought to be highly threatened, but are known from several locations (see *Craugastor glaucus*, page 196, and *C. pozo*, page 255—both of which are listed as CR). Finally, the fact that this region contains no federal protected areas, continues to undergo habitat destruction, and chytridiomycosis is known to be present (A. Muñoz, pers. comm.) makes it likely that *C. taylori* is deserving of a CR listing.

Exerodonta bivocata (DD) and *Duellmanohyla chamulae* (EN) would fall within the Pueblo Nuevo site, but neither would serve as additional trigger species. *Exerodonta bivocata* would not qualify as an AZE trigger because, like *C. taylori*, it is not EN or CR on the Red List. It is possible *E. bivocata* will be listed in one of the higher threat categories in the future. Johnson *et al.* (2010), speaking in the context of Red List assessments, stated that "because of the severe loss of humid forests in the region, the species undoubtedly is Critically Endangered" (pg.353). Furthermore, the known *E. bivocata* records support a much narrower distribution for the species than the polygon mapped by the Red List (Santos-Barrera 2004b). On first glance, *D. chamulae* would appear to be close to qualifying as an AZE trigger. It is similar to *E. bivocata* in that most of the known specimens are from a smaller area than is mapped by the Red List (Santos-Barrera & Muñoz Alonso 2004). However, its discovery in Veracruz on the N border of Oaxacan Chimalapas (Aguilar-López *et al.* 2010) shows that the distribution of *D. chamulae* is not well known and it is most likely too widespread to be considered as an AZE trigger.

Another species of importance here is *Plectrohyla ixil* (CR), which is known from this site and from a small area in Guatemala. The Red List account for *P. ixil* stated that "there is no information on its population status in Guatemala" and that it was "considered rare in Chiapas" (Santos-Barrera *et al.* 2006b). Such uncertainty about Guatemala might tempt us to list *P. ixil* as a trigger for Pueblo Nuevo alongside *P. pycnochila*. However, the species was photographed in 2009 at San Jose Maxbal, Barillas, Huehuetenango by Carlos R. Vasquez-Almazan and again at the same place by Sean Rovito.[4] In following up with Rovito, we are encouraged about this species in both locations. It is still a very localized species that is likely at risk from a number of threats, but it is unlikely to qualify as an AZE trigger. Rovito reports that *P. ixil* is "quite common both north of Pueblo Nuevo and at a site near Tapalapa, Chiapas". More specifically, the species may, like its presumed sister species, *P. matudai*, be relatively unaffected by *Bd* (as noted by Cheng *et al.* 2011). Rovito states "the population of *P. ixil* near Pueblo Nuevo Solistahuacán is infected with *Bd* (and has been for years), yet there are tons of frogs. I have seen *P. ixil* at multiple localities in Chiapas (as recently as August 2013) and Guatemala, and all populations appeared to be healthy with large numbers of adults" (S. Rovito, pers. comm.).

Anolis hobartsmithi (EN) is endemic to the highlands of northwestern Chiapas and occurs in the Pueblo Nuevo site. The current Red List range is probably too large for *A. hobartsmithi* to be considered an AZE species (see Muñoz-Alonso 2007a). However, the Red List map is much larger than the proven distribution of the lizard. Looking at the description of its range in Köhler (2008) and online KUH and MCZ records, *A. hobartsmithi* would appear to occur within a very small area that would be a single manageable site (ANSP also has a number of records, but they do not show locality data). Available records are from several kilometers S of Rayón and W of Pueblo Nuevo Solistahuacán. These two towns are close to one another, but the directions S of Rayón and W of Pueblo Nuevo converge on the same point. In other words, all records of *A. hobartsmithi* are from a very small area, and we suspect the species is best treated as an additional trigger for the Pueblo Nuevo AZE site.

AZE Site: Cerro de las Flores

Description

This site is triggered by the frog *Plectrohyla ephemera* (CR), which was described from a single adult and tadpoles in 2005 from Cerro de las Flores. The species was too recently described to be placed on the Red List in time for the 2005 AZE list of

[4] These photographic records were viewed at CalPhotos <http://calphotos.berkeley.edu/> on 31 May 2014.

sites, but it clearly qualifies (see page 213 for more about this site).

AZE Site: San Vicente Lachixío

Description

This site is triggered by the salamander *Pseudoeurycea anitae* (CR). *Pseudoeurycea anitae* was listed as DD on the 2004 Red List, and therefore was not included on the 2005 AZE list.

In addition to *Pseudoeurycea anitae*, *Plectrohyla labedactyla* (DD) is known only from San Vicente Lachixío, where a single individual was collected (Santos-Barrera & Canseco-Márquez 2004d). We recommend that the listing of DD for *Pl. labedactyla* be changed to CR. This species was collected 9 August 1976 by Ted Papenfuss (CAS 142596). The same day that Papenfuss discovered *Pl. labedactyla* at San Vicente Lachixío, he collected five individuals of *Ps. anitae* (MVZ 137935–39). At least 41 additional individuals of *Ps. anitae* have been captured over the years,[5] yet *Pl. labedactyla* has only been seen the one time despite many visits to the area by herpetologists. We think it is reasonable to assume that *Ps. anitae* and *Pl. labedactyla* face the same threats, and we agree that CR is the proper listing for the former. Were its listing changed to CR or EN, *Pl. labedactyla* would qualify as a trigger species for the San Vicente Lachixío site along with *Ps. anitae*.

AZE Site: Subcuenca Lago del Viejo

Description

This site in southern Chiapas is triggered by the frog *Craugastor montanus* (EN) and the bat *Rhogeessa genowaysi* (EN). *Craugastor montanus* was apparently overlooked for AZE (2005), and *R. genowaysi* had previously been listed as VU, thus not qualifying as a trigger species. When JFL submitted AZE candidate species for AZE (2010) he included the two species, however, he considered them to be triggers for separate sites: one for *C. montanus* in the mountains and one for *R. genowaysi* in the lowlands. We do not know the reason why the two sites were combined or the origin of the site name for AZE (2010). The literature concerning the distribution of both species is confusing.

Distributional uncertainty with regard to *C. montanus* is due to the fact that published records for the species exist from a disjunct locality to the northwest at Cerro Tres Picos, and there is at least one record from Guatemala. To qualify as a trigger species, *C. montanus* needs to be overwhelmingly from a single site—which is how

[5] AMNH 78654–57, 76365–67; MSB 32172–203; UCM 49297, 52597.

it currently appears to be on the Red List.[6] D. E. Breedlove collected 22 specimens of *C. montanus* at Cerro Tres Picos from 1972–1973,[7] and the specimens were examined by Lynch (2000) as part of a detailed study of the species, presumably serving as the basis for the latter's description of the range being "at moderate to intermediate elevations (1200-1900 m) on the Sierra Madre of Chiapas, Mexico" (pg.136). The Red List uses this exact elevational range, but restricts the species to the Cerro Ovando area without explanation (Santos-Barrera & Flores-Villela 2004). Such a disjunct distribution would not be terribly unusual, and the species would likely still qualify as EN were the Cerro Tres Picos records accepted—*Plectrohyla lacertosa* (EN) in fact has a distribution similar to this. Of course, even if the records from Cerro Tres Picos were to be considered valid, there would be a need to confirm that *C. montanus* was still present at the locality. Like the Cerro Tres Picos records, the specimen from Guatemala is difficult to dismiss without further investigation. Crawford and Smith (2005) used the specimen (UTA A-51105) in their review of the phylogenetics of Central American *Eleutherodactylus*, which elevated *Craugastor* to genus rank affecting *C. montanus*, as well as numerous other species. There is also a photograph of the species from Volcán Tacaná by A. Ramírez Velázquez in Köhler (2011: fig. 396, pg.169). Obviously, the Red List ought to double-check the distribution of this species, and if it is still considered to be only known from a single site the other records should be discussed.

The geographic range of *R. genowaysi* is even less straightforward than for *C. montanus*. The Red List account for *R. genowaysi* cites Simmons's (2005) description of the species' range as "Pacific lowlands of south Chiapas" (Arroyo-Cabrales & Ticul Alvarez Castaneda 2008). The actual known range of the species, however, is only from two localities "23.6 mi by road (Mex. Hwy 200) northwest of Huixtla," with the two localities being "at most a few kilometers apart" (Baker 1984:178). This is a very limited distribution. The Red List also says that "it is found only in a very restricted State protected area" (Arroyo-Cabrales & Ticul Alvarez Castaneda 2008). The protected area is not named, but it gives further support to the idea that the species is known from a single manageable unit.

The literature contains further confusion regarding the distribution of *R. genowaysi*. Arroyo-Cabrales and Baker (2005) map the species as inhabiting nearly the entire Pacific lowland plain of Chiapas. This may ultimately prove to be an accurate representation of the distribution, but to date *R. genowaysi* has only been recorded from outside of Huixtla. The Red List maps *R. genowaysi* as a single polygon that

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[6] Also, the taxonomic authority listed for *C. montanus* is incorrect on the Red List—"(Lynch, 1965)" should be (Taylor, 1942).

[7] CAS 170008–12, 170014–15, 170040, 170045, 170049–50, 170052–53, 170055–56, 170058, 170060, 170062–65, 170067. The specimens are listed as *Eleutherodactylus sartori*, which Lynch (1965) treated as a synonym of *C. montanus*.

is close to Huixtla. However, it does not actually include the known records and most of the map consists of the highlands that are inappropriate given that the bat is only known from a "few meters above sea level" (Baker 1984:178). The worst map is that of Roots and Baker (1998) that restricts *R. genowaysi* to Guatemala. The text of Roots and Baker (1998) makes it clear that this must be a mapping error, but it does add to the fact that each map in the literature is very different and none accurately represents the known records.

The listing of *R. genowaysi* as EN is based in part on its EOO of <5,000 km^2. Arroyo-Cabrales and Ticul Alvarez Castaneda (2008) must have deemed the probable distribution as being substantially larger than the known distribution. We believe this optimism is unwarranted given that the species has not been located since 1981, while habitat destruction in coastal Chiapas has increased steadily over the past 30 years. *Rhogeessa genowaysi* should probably qualify as CR (having an EOO of <100 km^2 with the same threats). Regardless of whether it is listed as EN or CR *R. genowaysi* still represents a trigger species.

We have included *R. genowaysi* (along with *C. montanus*) in a site called Subcuenca Lago del Viejo to be consistent with AZE (2010). We do not know the name of the state protected area from which it is known. If the protected area happens to be Subcuenca Lago del Viejo, then it is a well-chosen name for the site.

AZE Site: Centro Sierra Triqui-Mixteca

Description

This site is triggered by the salamander *Bolitoglossa riletti* (EN). Despite being listed as EN on the 2004 Red List, *B. riletti* was not included on the 2005 AZE list.

AZE Site: Sierra de Miahuatlán

Description

This site is triggered by *Eleutherodactylus syristes* (EN). The Red List maps *E. syristes* as being limited to a single polygon in the Sierra de Miahuatlán of Oaxaca (Santos-Barrera & Canseco-Márquez 2004e). We are unsure whether or not this polygon constitutes a single site. However, until more information is gathered about the distribution of the species and the manageability of the region, *E. syristes* should probably be considered a trigger species.

Box IV-1. Commentary on the Delineation of Sites in Northern Oaxaca

The mountains of northern Oaxaca have many shared biological characteristics. In 2008, AZE briefly lumped all ten of the northern Oaxaca sites from Ricketts *et al.* (2005) together as a single site on their website, thus including: "Ayutla," "Totontepec I," "Totontepec II," "Totontepec III," "Cerro Pelon I," "Cerro Pelon II," "Cerro Pelon III," "Northern slopes of Sierra de Juarez," "Sierra Norte," and "Concepción Pápalo." We agree that ten separate AZE sites in this region was too many, however, a single site neither adequately captures the character of the region nor is it manageable as a single unit.[1] Above, we proposed cutting the ten sites to five total, expanding Sierra de Juárez to include Cerro San Felipe, and listing a new site to the region (see page 237 for the delineation of Cerro de las Flores). AZE (2010) follows our arrangement with the exception of Ayutla, which we retain as a separate site, and they lump with Totontepec in a site called Sierra Norte de Oaxaca II. For a comparison of what we consider AZE sites for our region and those of AZE (2010) see Figure IV-5.

If the 2008 single site was adopted for northern Oaxaca, the list of AZE species would be amazingly large, including 28 amphibian AZE species (Table IV-2). Several species in other taxa would also qualify, which would put the total at 37 (Table IV-2). If one excludes Mexico, only four countries have more AZE trigger species within their boundaries than this super site (Colombia with 70; Peru 45; Ecuador 41; Indonesia 41) (AZE 2010). Cuba comes close with 30, so do Madagascar and Brazil with 28 each. Comparisons really start to become crazy when one considers that such a site would have four times the number of AZE trigger species as the Philippines and six times the number of Costa Rica (AZE 2010). The fact that lumping all of the northern Oaxaca sites into one produces an extraordinary list of AZE trigger species does not discourage us in terms of delineation, rather it demonstrates that the stakes of getting the delineation right are high.

Biologically, lumping the sites into a single polygon is defensible. It has been argued that the Sierra de Juárez (as we have defined it) is linked with the Sierra Mixe (including Totontepec) (Campbell & Frost 1993).[2] Concepción Pápalo and Sierra de Juárez have been considered a

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[1] Unlike AZE (2005) or AZE (2010), none of our authorship (JFL, MWM, RCH) worked on the brief 2008 arrangement.

[2] Campbell and Frost (1993) made the case for a biogeographical connection between the two sites when arguing that *Abronia kalaina* (from Sierra de Juárez) was a junior synonym of *Abronia fuscolabialis* (EN) (from Sierra Mixe)—their paragraph describing this connection mistakenly reversed the origin of the specimens, but the case for the connection is easy to understand: "the major entrenchment between these mountain ranges is the valley of the Río Cajones, although a cloud forest corridor extends along its headwaters between the Sierra Juárez and Sierra Mixe. Because the cloud forest is continuous between these two peaks it is not surprising that many highland species of amphibians and reptiles are shared among them, including *Pseudoeurycea juarezi*, *Hyla chaneque*, and *Exiliboa placata*" (Campbell & Frost 1993:42). All of these species are still thought to be shared between the two sites (note *H. chaneque* is now known as *Charadrahyla nephila* in northern Oaxaca following Mendelson & Campbell 1999). Specimens of *P. juarezi* from the two regions, however, still need to be

single biogeographic unit (Hanken & Wake 2001; Canseco-Márquez & Parra-Olea 2003) as have these two plus the Sierra Mazateca (Parra-Olea *et al.* 2005a). The opposite, however, has been argued as well. León Paniagua and Morrone (2009), for instance, concluded that most of these areas were biologically distinct. None of the studies was solely concerned with mapping CR and EN species, but just focusing on these species could bring other problems.

For us, the delineation of the northern Oaxaca AZE sites comes down to manageability. This is fitting because the AZE definition of a site is based on what is geographically and biologically distinct, as well as what is manageable. We are by no means certain of the lines we have drawn in this region, but they make sense to us as five sites (Figure IV-2; A, B, C, D, and J on the map). The least distinct of the sites is probably Cerro San Felipe and Cerro Pelón, which we combine and call Sierra de Juárez. A strong case could be made that these two should be separated. A few of the hylid frog species have been found in the two areas. Cerro San Felipe, however, is drier and it appears as though only one of the AZE salamanders, *Pseudoeurycea smithi*, has been recorded from both. The Cerro Pelón portion is already managed as a single unit and encompasses (or very nearly so) some species like *Thorius arboreus*, which is mapped by IUCN as four polygons even though these are all collecting localities within the same contiguous forest. Our combined Sierra de Juárez site is accessed by the same highway from Oaxaca City and could conceivably be managed as one. Concepción Pápalo is somewhat of a mountain isolate. The people speak a different language that belongs to a separate language family than the rest of the northern Oaxacan sites. The parts of the mountain containing the AZE species at Concepción Pápalo are drier than all but the Ayutla site (and possibly Cerro San Felipe). It also takes a tremendous amount of time to reach Concepción Pápalo from Cerro San Felipe, which represents the nearest portion of the closest site, Sierra de Juárez.[3] The Totontepec site contains five trigger species.[4] It too takes a lot of time to reach by road from Cerro San Felipe. Ayutla is much closer to Totontepec and the people of both areas are Mixe. However, Totontepec's cloud forest vegetation facing the Caribbean slope is so dramatically different from the dry pine forests around Ayutla that one feels as though you have entered another country. The two sites could possibly be managed together, but with the differences in habitat and the fact that no species would be added by the combination of the

looked at more closely with DNA (G. Parra Olea, pers. comm.) as does *Thorius macdougalli* (Hanken & Wake 1994), a species that was not mentioned by Campbell and Frost (1993). Another salamander, *Pseudoeurycea boneti*, is shared, but its distribution is wider than just the two sites (see Parra-Olea *et al.* 2005b). Other species thought to be shared, such as *Plectrohyla sabrina* (e.g., Toal & Mendelson 1995), have been shown to occur only in one of the two sites (in this case just Sierra de Juárez with the specimens from the Sierra Mixe being reassigned to either *Plectrohyla psarosema* or *Plectrohyla cyclada*, Campbell & Duellman 2000).

[3] To put this in perspective, by car it takes roughly the same amount of time to travel between these two sites as it does to drive the highway from Oaxaca City to Mexico City.

[4] This alone is a high number; biodiversity strongholds such as Uganda have 3 trigger species while Costa Rica contains 5 (AZE 2010).

two sites there would appear to be little gained by making them one.

Our proposed division of the northern Oaxaca sites has the disadvantage of excluding six highly threatened species from the AZE list that would have qualified under the brief 2008 arrangement: *Incilius spiculatus* (EN), *Plectrohyla cyclada* (EN), *Pseudoeurycea juarezi* (CR), *Peromyscus melanocarpus* (EN), *Abronia fuscolabialis* (EN), and *Mesaspis juarezi* (EN).

Table IV-2. List of species that would trigger a greater northern Oaxaca mountain AZE site. Twenty-eight amphibian species and nine non-amphibian species would trigger such a site. We do not advocate for a mega-site that includes all 37 of these species; however, a reasonable case could be made that such a site is warranted.

Amphibians

- *Craugastor polymniae*
- *Duellmanohyla ignicolor*
- *Ecnomiohyla echinata*
- *Incilius spiculatus*
- *Megastomatohyla mixe*
- *Plectrohyla calthula*
- *Plectrohyla calvicollina*
- *Plectrohyla celata*
- *Plectrohyla cyanomma*
- *Plectrohyla cyclada*
- *Plectrohyla ephemera*
- *Plectrohyla hazelae*
- *Plectrohyla psarosema*
- *Plectrohyla sabrina*
- *Pseudoeurycea aquatica*
- *Pseudoeurycea juarezi*
- *Pseudoeurycea mystax*
- *Pseudoeurycea orchileucos*
- *Pseudoeurycea saltator*
- *Pseudoeurycea smithi*
- *Pseudoeurycea unguidentis*
- *Thorius adelos*
- *Thorius arboreus*
- *Thorius aureus*
- *Thorius boreas*
- *Thorius papaloae*
- *Thorius pulmonaris*
- *Thorius smithi*

Mammals

- *Habromys chinanteco*
- *Habromys ixtlani*
- *Habromys lepturus*
- *Megadontomys cryophilus*
- *Microtus oaxacensis*
- *Microtus umbrosus*
- *Peromyscus melanocarpus*

Reptiles

- *Abronia fuscolabialis*
- *Mesaspis juarezi*

Two Additional AZE Sites Triggered by Non-amphibians

The following two sites were listed on AZE (2010).

AZE 2010 Site: Huitepec - Los Alcanfores

Description

Huitepec - Los Alcanfores is triggered by the San Cristóbal Shrew (*Sorex stizodon* CR) (see Cuarón *et al.* 2008). The site is named in part for Reserva Ecológica Huitepec, a protected area managed and owned by the NGO, Pronatura-Sur. Reserva Ecológica Huitepec was created in 1987 as the first privately owned protected area in Mexico. It lies 4–6 km outside of San Cristóbal de las Casas along the road to Chamula. The reserve covers an area of 136 ha and predominately consists of pine and oak montane forest from 2230–2710 m asl (Ramírez-Marcial *et al.* 1998).

E. W. Nelson and E. A. Goldman collected a single female of *S. stizodon* from San Cristóbal de las Casas in 1895 (Merriam 1895). Unfortunately, no further information about the type locality exists. It could, for instance, have come from one of the many areas in the Jovel Valley that used to be wild, but is now a section of the city, or it could have originated from a hillside such as the one containing Reserva Ecológica Huitepec. For more about San Cristóbal de las Casas and the surrounding area, see page 195.

Sorex stizodon went unseen for more than 100 years (Carraway 2007). Naranjo and Espinoza Medinilla (2001) reported finding the species within Reserva Ecológica Huitepec during their 1991–1998 mammal survey. It is unclear exactly when Naranjo and Espinoza Medinilla (2001) encountered *S. stizodon* and how many individuals they found. Because Reserva Ecológica Huitepec is the only known locality for *S. stizodon* we recommended that it be listed as an AZE site.

AZE Site: Mar Muerto-Pereyra

Description

This site is triggered by the Tehuantepec Jackrabbit (*Lepus flavigularis* EN) and the Oaxaca Spiny-tailed Iguana (*Ctenosaura oaxacana* CR). Both species consist of fragmented populations inhabiting lowland dry, scrub forest in the southern part of Oaxaca's Isthmus of Tehuantepec. JFL recommended against the inclusion of *L. flavigularis* for the 2010 AZE list because at a glance its four populations were hard to view as a cohesive site. The editors of AZE (2010), however, were confident that the range of *L. flavigularis* was manageable as a single area, and that if a site were formed for *L. flavigularis* it should also include *C. oaxacana*. Although we drove through this region on numerous occasions, we have little understanding of it in

terms of conservation and are satisfied with AZE's (2010) designation of the site. The site is certainly important biologically in that it contains numerous endemic species from other taxa and it is highly threatened by human activities.

More work is needed to understand the origin of the separate populations of each of the two trigger species and to determine their conservation needs. *Lepus flavigularis* was known to have low genetic variation within a population (Cervantes *et al.* 2002). Rico *et al.* (2007) confirmed these findings, but also discovered that one of the four populations was genetically distinct from the other three.[8] They determined that the two sets of *L. flavigularis* represent evolutionarily significant units and merit conservation attention in their own right. The separation of the two populations could have taken place in a number of ways. The molecular phylogenetics of *C. oaxacana* has also been studied and again the origins of populations within the region are a question that might have conservation implications (Hasbún *et al.* 2005).

Possible AZE Trigger Species Depending on Site Definition

Eleven species (1 conifer, 4 amphibians, 3 reptiles, 3 mammals) might qualify as AZE triggers depending on questions of distribution and/or site definition. JFL listed most of these as "unsure" during the AZE site review process for the 2010 revised list. In many cases, uncertainty regarding these species/sites could be resolved with information either from experts or by basic field work. We did not seek these species as part of our project, but we found two of them while searching our sites: *Plectrohyla acanthodes* and *Pseudoeurycea juarezi*. We include a few words about the 11 species because the determination of their AZE status is extremely important to the region (*P. acanthodes* and *P. juarezi* are discussed in greater detail elsewhere).

Conifer

Juniperus standleyi (EN) – although this species was assessed in 2011 there is still no map available on the IUCN Red List (Farjon 2013). The range description for *J. standleyi* on the Red List states that the species is known from two locations, "Chiapas (Volcán Tacana); and Guatemala: Huehuetenango, San Marcos

[8] The distinct population is the Santa María del Mar population, and until recently it was thought to be the only one still in existence. Lorenzo *et al.* (2006) discovered the other three populations and reported their total area to be 67 km^2, which is what the Red List used as the area of occupancy (Cervantes *et al.* 2008). However, the Santa María del Mar population should be added to the total. Rico *et al.* (2008) cite "Carrillo, unpublished data" for the area of this population being 40.5 km^2. Changes to the area of occupancy would not affect the IUCN listing.

(highlands)." JFL did not give a recommendation to AZE about this species (marking it as "unsure"). AZE (2010) included *J. standleyi* as a trigger for the Guatemalan/Mexican Pacific Coastal Mountains site.[9]

Adams (2011) contains what appears to be a good summary of the species, including a range map that shows the species barely entering Mexico. In reference to the EN listing by IUCN, Adams (2011:308) states "it seems more likely that it is vulnerable than endangered." Farjon (2013) mentions this opinion, but argues that EN is warranted.

Amphibians

Exerodonta chimalapa (EN) – the Red List maps this species as being limited to a single polygon in Chimalapas on the border of Chiapas and Oaxaca (Muñoz Alonso & Canseco-Márquez 2004). AZE (2010) considered the greater Chimalapas region to be an AZE site (called Selva Zoque I), and *E. chimalapa* was one of its trigger species. As mentioned above and discussed in our Chimalapas site account (page 181), we disagree with this delineation, but it is a difficult judgment call to make.

Because the range of *E. chimalapa* overlaps the Chimalapas AZE site, we were often within the range of *E. chimalapa*, but failed to locate it. This is not an indication that the species is particularly hard to find as we were not targeting our searches for it. We know of others who have found *E. chimalapa* here in recent years. Records within its polygonal range have been scattered among several localities.

Plectrohyla acanthodes (CR) – this species does not qualify for AZE status, though a case for its inclusion could be made based on the information in the current Red List account. It was not considered a trigger by AZE (2010). We managed to find *P. acanthodes* and discuss it further elsewhere (see page 201).

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[9] The name of this site, Guatemalan/Mexican Pacific Coastal Mountains, would imply that a portion of it occurs in Mexico, but this is not the case. AZE (2010) maps the site as being entirely within Guatemala. Of the site's three trigger species, *J. standleyi* is the only one that is known to occur within Mexico. This means that the site either should be expanded slightly to incorporate part of Mexico or should be restricted to the portion containing *Oedipina stenopodia* (EN) and *Dendrotriton bromeliacius* (CR). We favor the expansion of the site and recommend the consideration of *Incilius tacanensis* (EN) and *Abronia matudai* (EN) as additional trigger species. We discuss *A. matudai* in the text below. The Red List status of *I. tacanensis* should be reviewed. We suspect chytridiomycosis is the primary threat to *I. tacanensis* and the fact that "there are no recent records of it in either Mexico or Guatemala, despite searches" (Santos-Barrera *et al.* 2004) might warrant a listing of CR. In any case, the geographic range of the species would be consistent with a slightly expanded (into Mexico) delineation of the Guatemalan/Mexican Pacific Coastal Mountains site. The smallest expansion in fact would be to add just Volcán Tacaná to the site, thus including *I. tacanensis* and *A. matudai*. As Johnson *et al.* (2010) pointed out, Volcán Tacaná is geologically and faunalistically part of Guatemala.

Pseudoeurycea juarezi (CR) – this species probably does not qualify for AZE status and it was not considered a trigger by AZE (2010), but more information is needed. We found this species and discuss it further elsewhere (see page 135).

Ptychohyla macrotympanum (CR) – this is a curious case. The Guatemalan AZE site, Cuilco, is triggered by *P. macrotympanum* (AZE 2010), but we question this designation. The Red List map and species account support *P. macrotympanum* as a trigger species—listing Cuilco ("La Cumbre") as the only location for the species (Acevedo & Young 2004). However, the type locality and the bulk of records for *P. macrotympanum* are from Chiapas where it has a relatively large distribution (Tanner 1957; Duellman 1961; Duellman 1963; Campbell & Smith 1992). The Mexican records are neither mapped nor mentioned in the species account, and Mexico is said to be "presence uncertain" under the list of countries (Acevedo & Young 2004). It is possible that *P. macrotympanum* has disappeared from Chiapas, but the Red List gives no indication of this (and it is unlikely; Johnson *et al.* 2010 list the species in three separate physiographic regions of Chiapas and as a species typical of Tzama Cum Pümy, Chiapas).[10] Another minor problem with the Red List account is that the taxonomic authority is incorrectly listed as Campbell and Smith (1992); it should be Tanner (1957). Normally an incorrect species authority would not be worth mentioning, but it casts additional uncertainty about this particular Red List account's reliability. IUCN should reassess *P. macrotympanum*.

Reptiles

None of the reptiles listed below belong to the taxonomic groups that have been globally assessed by IUCN. For this reason, none of them were considered for the AZE (2010) species list, but these could be considered for a global AZE list in the future when reptiles have been comprehensively assessed.

Abronia matudai (EN) – the species is mapped by the Red List as two polygons (Campbell & Muñoz-Alonso 2013). It also states that in Guatemala, *A. matudai* is known only from two collecting localities on the Pacific versant near San Marcos. In Mexico, the species is known only from Volcán Tacaná, showing it to be similar to *Incilius tacanensis* (EN) in terms of distribution.

Anolis breedlovei (EN) – the Red List maps this as a single polygon in Chimalapas

[10] We noticed a similar problem with *Craugastor stuarti* (EN), which is mapped on the Red List as being in Guatemala and a tiny portion of Mexico (Santos-Barrera & Acevedo 2004) despite the fact that there are numerous records from elsewhere in Chiapas (we have seen some of these in the INHE collection, Johnson *et al.* (2010) list the species from two physiographic regions of Chiapas that are outside the Red List range map, and Streicher (2012) lists a record from near Pueblo Nuevo along Highway 195). This species needs to be reassessed by IUCN, but more importantly there should be a review of Guatemalan species generally to be sure that the problem is not widespread.

that is similar to that of *Exerodonta chimalapa*, though the two do not overlap (Canseco-Márquez & Muñoz-Alonso 2007). Like that species, the Red List data for *A. breedlovei* would support an expansion of the Chimalapas site from the way we define it were the species considered an AZE trigger (see page 181). However, *A. breedlovei* has two added wrinkles that could be of importance. When Smith and Paulson (1968) described *A. breedlovei*, most of the paratypes came from a small area near Pueblo Nuevo. It was found again near Pueblo Nuevo in 1969 by Robert G. Webb (MSUM HE.11606 and HE.11608). We know of no reason to exclude this portion of the species' range. We suspect, therefore, that *A. breedlovei* does not qualify as a trigger, being similar to other species having a Chimalapas–Pueblo Nuevo distribution (e.g., *Charadrahyla chaneque* EN). Also, the species might be a junior synonym for *Anolis cuprinus* (LC) (Nieto-Montes de Oca *et al.* 2013).

Lepidophyma lipetzi (EN) – the Red List states that this species is known only from the type locality of "Presa Mal Paso, 30 km N Cintalapa," Chiapas (Muñoz-Alonso 2007b). The mapped range, however, is much larger than a type locality. On HerpNET (2014) there is only one record of *L. lipetzi*, which is the holotype collected in 1973 (UCM 51425). But there are seven records in ECOSUR-SC that appear on REMIB (2014)—six of which come from two localities within Reserva Ecológica El Ocote and the precise locality of the seventh is unclear (ECOSUR-SC 0001, 0018, 0045, 0147, 0161–62, 0712). These records are extremely important. They make the Red List range map intelligible and support IUCN's EN listing. With the threats listed, *L. lipetzi* would qualify as CR were it truly known only from the type locality. From the ECOSUR-SC records we also know that the species is not an obligate cave dweller, which was considered a possibility when the species was first described (Smith & Álvarez del Toro 1977).

There is some confusion about the type locality, especially concerning its protected status. It was reported to be a cave on the edge of the reservoir. However, the map in Smith and Álvarez del Toro (1977) has the Rio Negro intersecting the lake directly, which is incorrect. More perplexing is the fact that the boundary of Reserva Ecológica El Ocote varies so greatly depending on the source that it is hard to tell whether the type locality falls within the protected area or not. For example, the classic, albeit famously inaccurate road atlas, Guía Roji, maps the reserve all the way north to border of Presa Nezahualcóyotl (Roji García & Roji García 2004), the Instituto Nacional de Ecología maps parts of the reservoir edge as within El Ocote (Instituto Nacional de Ecología 2010), and the *World Database on Protected Areas* shows the reservoir edge as barely touching a corner of the reserve (IUCN & UNEP 2014).

Mammals

Megadontomys cryophilus (EN) – the Red List map places the entire range of this species within the Sierra de Juárez AZE site (Álvarez-Castañeda & Castro-Arellano 2008a), and the map is obviously drawn along an elevational contour that is larger than the proven distribution of the species here. For these reasons, *M. cryophilus* would at a quick glance qualify as an AZE trigger. The distribution of the species, however, is not that straightforward.

Megadontomys cryophilus occurs in Concepción Pápalo as well as the Sierra de Juárez (Vallejo & González-Cózatl 2012). The Red List account (Álvarez-Castañeda & Castro-Arellano 2008a) cites Musser and Carleton (2005) for its distribution, but Musser and Carleton mention records from the S. Mazateca and the S. Mixteca in addition to the Sierra de Juárez. These non-Sierra-de-Juárez records came from a series of elevational surveys (Briones-Salas *et al.* 2001, 2004; Sánchez-Cordero 2001). Without comment, Álvarez-Castañeda and Castro-Arellano (2008a) ignored the S. Mazateca and the S. Mixteca records and Vallejo and González-Cózatl (2012) subsequently have reported that these specimens were misidentified. Thus, the Red List account is correct, but it should add Concepción Pápalo (Vallejo & González-Cózatl 2012). It would also be useful if it included an explanation of why certain areas normally attributed to *M. cryophilus* (e.g., S. Mazateca and S. Mixteca) were excluded.

We doubt *M. cryophilus* qualifies as an AZE trigger species (thus being analogous to *Mesaspis juarezi*, see page 99), but there is still much uncertainty. JFL did not give a recommendation to AZE about this species (marking it as "unsure"). AZE (2010) included the species as a trigger for the Sierra de Juárez site and we have kept it on the list within the site account (page 105).

Tylomys tumbalensis (CR) and *Tylomys bullaris* (CR) – we begin by treating these species together because of a number of similarities they share. Based on information in the current Red List accounts, *T. bullaris* and *T. tumbalensis* would qualify as AZE triggers for sites Tuxtla Gutiérrez and Tumbalá, respectively. Both species are listed as CR and are said to be known only from their type localities (Álvarez-Castañeda & Castro-Arellano 2008b,c). There are, however, questions about the taxonomic validity and distribution of the species that might undermine their AZE status. This is an instance where certainty requires more information. On the whole, we believe the evidence supports a Tuxtla Gutiérrez AZE site triggered by *T. bullaris*; for the time being we think it should also support *T. tumbalensis* as triggering Tumbalá, but there are more questions about it that require investigation.

Tylomys bullaris and *T. tumbalensis*, like *Sorex stizodon*, were discovered by E. W. Nelson and E. A. Goldman in 1895, while they were conducting field work for

the Biological Survey of the US Department of Agriculture, and described by C. Hart Merriam. Both *Tylomys* were described from single immature male specimens (Merriam 1901).

Neither Red List account contains a taxonomic note that would indicate a question about their standing as species (Álvarez-Castañeda & Castro-Arellano 2008b,c). Musser and Carleton (2005) tentatively considered them to be full species following Hall (1981) whose statement about the group was that "study may show that some of the species are only subspecies" (pg.626). Reid (2009:222) took Hall's remark seriously, stating:

> "Two species, each known only from a single subadult specimen, occur within the range of *T. nudicaudus* in Chiapas, Mexico. Chiapan Climbing Rat (*Tylomys bullaris*) is known from Tuxtla Gutiérrez, at 550 m. Tumbalá Climbing Rat (*Tylomys tumbalensis*) is known from Tumbalá, at 1700 m. Both are distinguished by cranial characters only and will be described as subspecies of *T. nudicaudus* (Hall, 1981; T. Alvarez, personal communication)."

The two climbing rats are considered distinct species by the Red List, although they may be, or "will be," lumped into *T. nudicaudus* when a review of *Tylomys* eventually takes place. We do not have an opinion about the taxonomic validity of either species and believe it is prudent to follow the current Red List until such a review settles the matter. In the meantime, an equally serious question about the AZE status of these species hinges on their distributions.

Tylomys bullaris and *T. tumbalensis* are often said to be known from single locations (Álvarez-Castañeda & Castro-Arellano 2008b,c; Ceballos *et al.* 2009; Reid 2009), although they are known from multiple individuals. The type locality for *T. bullaris* was described simply as "Tuxtla, Chiapas, Mexico" (Merriam 1901). The most reliable locality for *T. bullaris* is a small population that lives freely within the grounds of ZOOMAT, the zoo in Tuxtla Gutiérrez; it is possible that the species might also occur within the nearby Sumidero Canyon (Espinoza Medinilla 2005). We know of at least two specimens in addition to the type specimen. One was collected two miles southeast of Tuxtla Gutiérrez by R. H. Pine in 1962 (TCWC 9407).[11] The other was collected by Eugene S. Hunn from "Yashanal, Tenejapa, 17 mi NE San Cristóbal de las Casas" 14 September 1971 (MVZ 141786). This latter record is surprising for its distance from Tuxtla Gutiérrez, but even more surprising is that it was from 1829 m in the Meseta Central—more than three times the ele-

[11] GBIF (downloaded 24 January 2010) lists another record from Tuxtla Gutiérrez collected by M. Alvarez del Toro, but no date is given for the specimen (IBUNAM-CNMA 3096).

vation of the other specimens. Until more such records are confirmed, we think it is wise to consider the species endemic to Tuxtla Gutiérrez.

Tylomys tumbalensis could possibly be widespread within Chiapas. In addition to the type specimen from Tumbalá (USNM 76059), it has been reported from El Ocote (Espinoza Medinilla *et al.* 1999a; SEMARNAT 2001). We know of four specimens from the forest of El Ocote, but it is not clear from the records we have seen whether these originated from within the El Ocote Biosphere Reserve (IBUNAM-CNMA 24480–24483).[12] Two specimens of *T. tumbalensis* have been found nearer to Tumbalá. One of these was collected by William Talbot at Agua Azul in 1985 (MSB 55652), the other is from "El Real, 2 mi E of" by R. W. Dickerman in 1955 (KUH 66640) (from Vertnet 2014). Finally, the species has been reported from the other side of the state at El Triunfo Biosphere Reserve (Espinoza Medinilla *et al.* 1998, 1999b), although we were unable to find specimen records matching this locality.

As stated above, the current Red List would support both *T. bullaris* and *T. tumbalensis* as AZE trigger species. The distributions of the two species, however, raise questions about them. Of the two, *T. bullaris* is more likely to qualify for AZE. While noting the need for more information about these species, JFL recommended that they be listed as AZE triggers and both appear on AZE (2010).

DD Amphibian Species that Might Qualify if Reassessed

In this section we are only concerned with species that could possibly trigger new AZE sites if their Red List status were reassessed. Additional DD species that might qualify for AZE and exist within current AZE sites are treated within the relevant site delineations or profiles. For example, we argued that *Craugastor taylori* should be listed as CR instead of DD, which if followed would make it an additional trigger for Pueblo Nuevo (page 234) so we do not discuss it here. We also do not discuss the numerous non-amphibian DD species.

Pseudoeurycea obesa was described from the Sierra Mazateca relatively recently (Parra-Olea *et al.* 2005a). The salamander is DD because more information is needed about its distribution as well as other aspects of threat, status, and habitat requirements. Although the species might prove to be more widespread, the Sierra

[12] These records appear via GBIF (2010) as being collected by "Galvan-S., J. V.," but without collection dates for three of them. IBUNAM-CNMA 24483 was collected 31 October 1986. Given the uniform sequence of numbers with the same "Galvan-S., J. V." listed as collector, it is likely that all four records are from the same time period, if not the same date.

Mazateca is somewhat isolated. With what is known of the threats to habitat in the region, *P. obesa* would likely become an AZE trigger if it proved to be confined to the current known distribution. We note, however, that the DD listing for *P. obesa* seems appropriate to us, and there is a possible hint in the Red List account that it will be found elsewhere: "future work might prove it to be more widespread than current records suggest" (Hanken & Wake 2008). Certainly the statement is equivocal, but it would not have been made if the authors of the account did not think this was a real possibility. *Pseudoeurycea ruficauda*, for example, is also recently described from the Sierra Mazateca (Parra-Olea *et al.* 2004) and listed as DD on the Red List, but it has since been found near Peña Verde, which is close to Concepción Pápalo (S. Rovito, pers. comm.). Thus, *P. ruficauda* is likely too widespread to be considered an AZE trigger species even if it were to be listed as EN or CR.

Three DD amphibians in the Sierra Madre del Sur of Oaxaca might qualify as AZE triggers if they eventually are listed as either EN or CR: *Bolitoglossa oaxacensis*, *B. zapoteca*, and *Plectrohyla miahuatlanensis*. The least likely of these to qualify as a trigger is *B. oaxacensis* because it is hard to characterize the salamander's range as a single manageable site. Indeed, *B. oaxacensis* is known from several localities along Highway 131 and from both sides of the Río Atoyac (Parra-Olea *et al.* 2002). The Red List account for *B. oaxacensis* also states that "it might occur more widely" (Parra-Olea *et al.* 2008b). In addition, the *P. miahuatlanensis* Red List account mentions *B. oaxacensis* as occurring at a disjunct location further to the east (Angulo 2008, following information in Meik *et al.* 2006), though this is neither mentioned nor mapped in the Red List account for *B. oaxacensis* by Parra-Olea *et al.* (2008b).

The other two Sierra Madre del Sur species are more likely to one day qualify. *Plectrohyla miahuatlanensis* is known from a single individual, thus the known distribution is a single point. Although *P. miahuatlanensis* was found in a relatively intact forest in 2001, much of the region has been cleared (Meik *et al.* 2006) and it would not be surprising if it were listed as highly threatened in the future. *Bolitoglossa zapoteca* is known from a very small area in the mountains near Quiegolani. Strangely, it is listed as DD on the Red List, while the Red List justification for the listing refers to the species as being NT (Parra-Olea *et al.* 2008c).[13] This species would be likely to be listed as EN or CR in the future if threats to its habitat were confirmed, and given its known distribution the species might ultimately qualify it as an AZE trigger. Sean Rovito found several individuals of *B. zapoteca* in 2013 at the type locality where he found the forest to be fairly intact

[13] This odd contradiction between Red List category and Red List justification occurs for other species in our region: *Pseudoeurycea cochranae* is listed as EN, but the justification has it as VU (Parra-Olea *et al.* 2008d) and *Cryptotriton alvarezdeltoroi* is also listed as EN with a justification that has it as VU (Parra-Olea *et al.* 2008a). In each of these cases we assume the listing, as opposed to the justification, to be correct.

(pers. comm.).

Two other DD amphibians in the region are worth mentioning. This is because their maps appear to make AZE status a possibility: *Ptychohyla acrochorda* and *Plectrohyla ameibothalame*.[14] Although mapped as a single polygon by Santos-Barrera (2004c), *P. acrochorda* is probably known from too many disparate localities to be considered an AZE trigger. Similarly, *P. ameibothalame* is known from two disjunct polygons that are more than 40 km apart (by air). The latter species, however, is known from a relatively few number of individuals and it is possible that if one of the two sites were eliminated the species would qualify as an AZE trigger. Still, the distributional limits of *P. ameibothalame* are not well understood and it is quite possible that it will be found at additional localities (Canseco-Márquez 2004).

Deleted Amphibian AZE Sites

These sites were listed as AZE sites when we began our project (AZE 2005). They were removed by AZE (2010).

Deleted AZE 2005 Site: "Cerros de San Cristóbal de las Casas"

For more about this site see "San Cristóbal de las Casas" on page 195.

Delineation

To the best of our knowledge, the 2005 AZE site "Cerros de San Cristóbal de las Casas" should not be listed as an amphibian AZE site. The site was originally triggered by two amphibians, *Plectrohyla pycnochila* and *Craugastor glaucus*. It is quite possible that *P. pycnochila* no longer persists in the mountains surrounding San Cristóbal de las Casas, and *C. glaucus* is too wide ranging to be considered a trigger species.

[14] The remaining DD amphibian species in the region—*Bolitoglossa stuarti*, *Craugastor amniscola*, *C. palenque*, *C. pelorus*, *Dermophis oaxacae*, and *Ptychohyla zophodes*—would all clearly be inappropriate for AZE consideration based on site delineation even if they were reassessed as EN or CR. *Pseudoeurycea maxima* is also DD and would likely qualify as an additional trigger species for the Centro Sierra Triqui-Mixteca site along with *Bolitoglossa riletti* (EN) were it to be placed in either EN or CR (page 240) based on the information in its Red List account. However, the Red List account states that "it is likely to be more widespread," and this appears to be correct (Wake *et al.* 2008). *Pseudoeurycea maxima* has subsequently been found in secondary forest at a higher elevation of 1086 m (up from 1030 m), 15.9 km N of San Gabriel Mixtepec, approximately 130 km SE of the type locality (Delia *et al.* 2008), and also from 2331 m about 87.02 km NW of type locality in Ejido Tres Marias, Municipality of Malinaltepec, Guerrero (García-Vázquez & Durán-Fuentes 2012). Thus, *P. maxima* would be too widespread to be considered an AZE trigger species regardless of threat category.

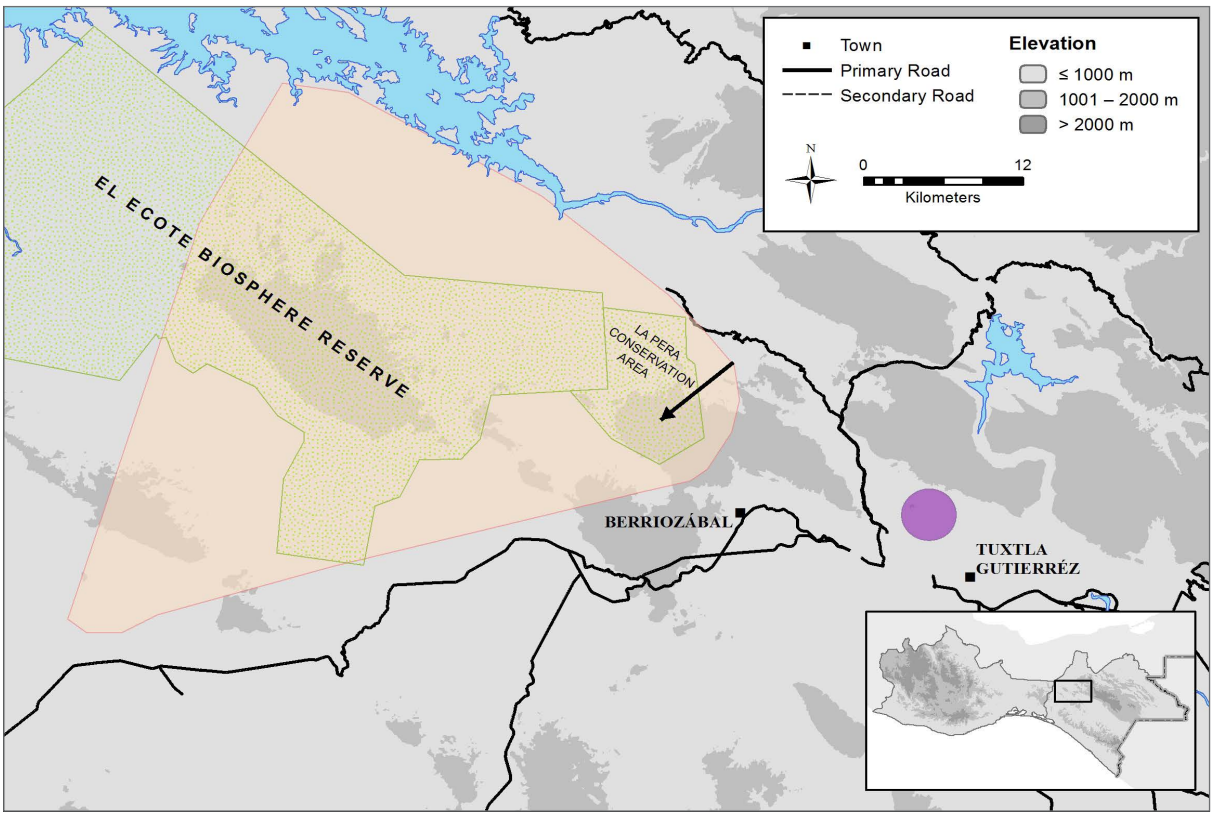

Fig. IV-7. Map showing the known range of *Craugastor pozo* (orange polygon). The purple circle represents the range of *C. pozo* according to the IUCN Red List (Santos-Barrera & Parra-Olea 2004); the black arrow indicates where we located *C. pozo* in El Pozo (within "La Pera Conservation Area").

Deleted AZE 2005 Sites: "Southwestern Chiapas" and "Corredor Laguna Belgica-Sierra Limon-Cañon Sumidero"

Delineation

We recommended the elimination of "Southwestern Chiapas" and "Corredor Laguna Belgica-Sierra Limon-Cañon Sumidero" from the AZE site list. These two sites overlap (with the former being enclosed within the latter) and should never have been considered separate entities. The "Southwestern Chiapas" site was triggered by the salamander, *Ixalotriton niger*, which was only known from a small forest called El Pozo (within the state protected area, La Pera Zona Sujeta A Conservación Ecológica). *Ixalotriton niger* was last seen in this forest more than a decade ago, despite considerable effort to relocate it in the intervening time. We think it is possible that the species no longer exists at El Pozo. Fortunately, the species has been found in the Chimalapas AZE site (see an expanded discussion of *I. niger* within Chimalapas, page 186). We think it is best to treat *I. niger* as an additional AZE trigger species for Chimalapas at least until it is found to have a viable population at El Pozo or another location. The "Corredor Laguna Belgica-Sierra Limon-Cañon Sumidero" site was triggered by the frog, *Craugastor pozo*, which, as its name suggests, is also found at El Pozo. *Craugastor pozo*, however, has been found in several additional locations, which is why "Corredor Laguna Belgica-Sierra

Fig. IV-8. El Pozo (top left). *Craugastor pozo* from El Pozo 11 June 2008 (rest of photos).

Limon-Cañon Sumidero" in effect contains the "Southwestern Chiapas" site. *Craugastor pozo* is analogous to *C. glaucus* above in that its distribution is not easily considered a single site.

Craugastor pozo (CR) – is named after its type locality, El Pozo (Johnson & Savage 1995) (see Box IV-2, page 258, for more on El Pozo). Baker *et al.* (1971) produced the first description of reptiles and amphibians from this locality. Apparently, *C. pozo* was known from El Pozo at that time, but the authors chose not to mention it because they were uncertain as to its identity (Johnson *et al.* 1976). Johnson *et al.* (1976) reported the frog as *Eleutherodactylus brocchi*, but the lead author later determined that the frog represented an undescribed species and referred to it as *Eleutherodactylus* sp. in Johnson (1989) before formally describing it six years later (Johnson & Savage 1995).[15]

[15] Presumably the undescribed leptodactylid from El Pozo mentioned by Wake and Johnson (1989) was also *C. pozo*.

The distribution of *C. pozo* is not straightforward. The Red List maps *C. pozo*'s range as a single polygon of 12.68 km^2 (matching the listing justification), but this does not coincide with the Red List's written description of the distribution (Santos-Barrera & Parra-Olea 2004). The species' account's written description matches that of Campbell and Savage (2000:212):

> "The western foothills and highlands of Chiapas, Mexico, in an area between Cintalapa, Berriozábal, and Presa Netzahualcóyotl … this species occurs at elevations of 760-1100 m."

The description of the species' range as being between three points begs at least two questions. First, is the species still found at these three points? And second, to what extent does the species occur in between the three points?

The answer to the first question is likely yes, with one caveat. We, as well as others, have found the species at El Pozo (roughly solidifying the Berriozábal point). The species is also known from the nearby locality of Parque Educativo Laguna Bélgica (Luna-Reyes *et al.* 2005). *Craugastor pozo* has been found at least twice near Cintalapa.[16] The third point was derived from collecting localities along the old road leading NW from Ocozocoautla approaching the reservoir (Presa Netzahualcóyotl). INHE has four records along this stretch of road, none of which is likely to be farther than the four specimens from 26 km N Ocozocoautla reported by Johnson and Savage (1995).[17] This old road winds, but even if we map a point that is directly 26 km N of Ocozocoautla we find that the point falls considerably short of where the road meets the reservoir.[18] Thus, the known records of *C. pozo* support the three points described by Campbell and Savage (2000), but the northern point should be moved slightly southward (Figure IV-7).

When we map this range as a polygon, *C. pozo* has an approximate EOO of 1,226 km^2 (Figure IV-7). Using this EOO and same subcriteria (B1ab(iii)), *C. pozo* would qualify as EN instead of CR. There is little evidence, however, that *C. pozo* is found throughout the polygon we have mapped. As far as we know, it has not been found within El Ocote Biosphere Reserve (the major protected area that lies in the middle of the species' EOO). El Ocote is similar to the other localities for *C. pozo* in that it

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[16] One being a paratype reported as "ca. 9 km NNE Cintalapa, Chiapas" by Johnson and Savage (1995:501) and the other an additional point reported as "3.2 km E Francisco Madero, N and E of Cintalapa" by Campbell and Savage (2000:212).

[17] One from 10 km NW de Ocuilapa, El Aguajito (INHE 3055, 3 Apr. 2002), and three others from 21 km N along the Ocozocoautla-Malpaso road (INHE awaiting catalogue numbers, Aug. 1981).

[18] We refer to this as the old road because a toll highway (cuota) is now in place that runs roughly parallel to the road along which the specimens of *C. pozo* were found.

is karstic with surface water being rare (a unifying theme for the points along this southern portion of the northern highlands). Much of El Ocote, however, is higher in elevation than the known localities for the species. On the whole, mapping *C. pozo* as three polygons (broadly similar to the three points mapped by Johnson & Savage 1995) or as a single polygon encompassing the three points is defensible. In either case, *C. pozo* does not qualify as having an EOO of less than 100 km^2 or being found from a single location, which currently are invoked as subcriteria for the CR listing (Santos-Barrera & Parra-Olea 2004). Therefore, we recommend a reassessment of *C. pozo* with it probably becoming EN. Additionally, the Red List conservation measures for the species should note that *C. pozo* is known from two small state protected areas, Parque Educativo Laguna Bélgica and La Pera Zona Sujeta A Conservación Ecológica. A research priority for the species should be to determine whether it exists in El Ocote.

As noted above, we do not believe *C. pozo* qualifies as an AZE trigger species because it is not found within a single manageable area. However, the species is still highly threatened by anyone's measure.

We located five individuals and estimated there to be at least 15 in total at El Pozo on 11 June 2008 (Figure IV-8). This was our only attempt at finding the species during the rainy season, and in fact it was during a light rain that we had success. We had sought *C. pozo* at El Pozo on numerous previous occasions during the dry season, but each time we failed to detect it.

Box IV-2. El Pozo

El Pozo is a particularly important locality that warrants some discussion (for a map showing its location, see the area indicated by the black arrow in Figure IV-7, page 254). El Pozo means "the well" in Spanish and was named for a PEMEX (Petróleos Mexicanos) test oil well that was drilled here. Presumably, El Pozo was shown not to be profitable in terms of oil as further exploration was abandoned. It falls within a protected area, La Pera Zona Sujeta A Conservación Ecológica (a state-level protected area designated in November 2006). The site is also known as "Pozo Turipache" or "Pozo La Pera" (Johnson & Savage 1995), "Linda Vista" (Wake & Johnson 1989), or just "La Pera" (Parra-Olea *et al.* 2008a).

El Pozo is traditionally considered part of a physiographic unit called the northern highlands of Chiapas as described by Müllerried (1957) and Breedlove (1973). Johnson (1989:15) stated that the northern highlands are "being rapidly exploited for agriculture and other natural resources," and this is still true today.

The forest itself sits atop a hill at about 1100 m and is approximately 12 km NW of Berríozábal, Chiapas (Figures IV-7 & IV-8). Lazcano Barrero (2000) estimated the size of El Pozo to be 50–100 hectares, but it has shrunk considerably since 2000. However, the La Pera Zona Sujeta A Conservación Ecológica, of which it is a part, is much larger. Ochoa-Ochoa and Whittaker (2014:538) describe the protected area as a whole as "7506 ha containing pristine and disturbed patches of two natural vegetation formations: tropical rain forest and evergreen seasonal forest." El Pozo might be representative of the disturbed portion. We witnessed not only cattle pastures advancing at the perimeter of the forest, but selective logging of the largest trees (which likely disrupts the balance of humidity) and a small agricultural plot that had recently been carved out of the forest's center. Ochoa-Ochoa *et al.* (2011) also mention local people removing leaf litter to sell as organic fertilizer as a major threat to *Craugastor pozo*. We presume the authors are speaking about this as occurring at El Pozo.

The climate of El Pozo appears to have changed in the last few decades. Johnson (1989) described the locality as montane rainforest. Wake and Johnson (1989) estimated the average annual rainfall at 3,000 mm with a consistent cloud cover:

> "Clouds usually cover the area beginning in mid- to late afternoon and lasting through early morning hours. During the dry season, clouds are sometimes absent." (pg.7)

In the year and a half over which we visited El Pozo, clouds were uncommon in the dry season. We are not botanists, but the forest at El Pozo no longer appears to be montane rainforest. Wake and Johnson (1989) described the surface layer as moist:

> "Even during the winter dry season sufficient precipitation falls to maintain moist conditions in the leaf litter on the forest floor, and in some years rainfall may be heavy." (pg.7)

It is possible that the past year and a half was anomalous, but the forest floor was only moist one time when we visited the site and that was because it happened to be raining.

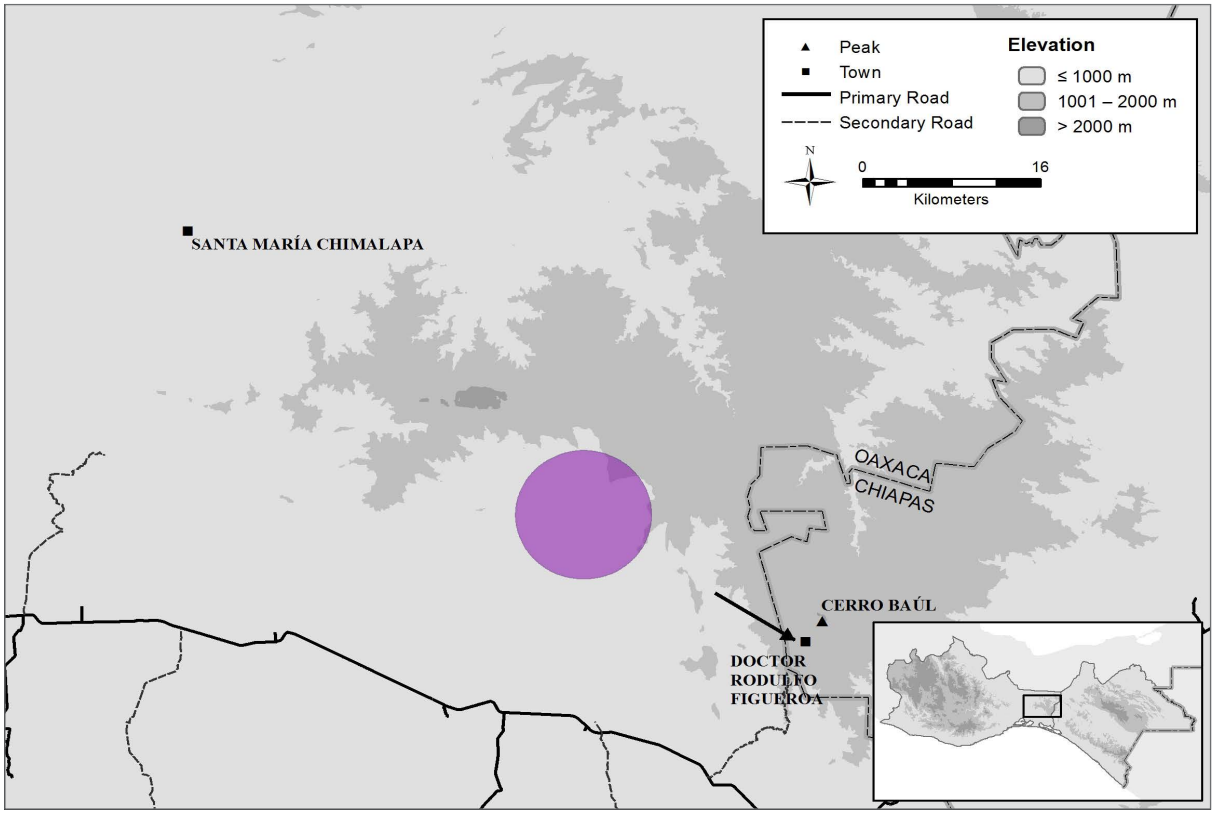

Fig. IV-9. The purple polygon represents the range of *Craugastor silvicola* according to the IUCN Red List, which approximates the type locality (Santos-Barrera & Canseco-Márquez 2004f). The black arrow indicates where we located the species. There is also a record from Chalchijapa, in the municipality of Santa María Chimalapa, which is north of the town, Santa María Chimalapa, shown above.

Deleted AZE 2005 Site: "Zanatepec"

Delineation

We recommended the elimination of "Zanatepec" from the AZE site list. This site was triggered by the frog, *Craugastor silvicola*. The known records for the species are probably too disparate to belong to a single site. AZE (2010) kept *C. silvicola* as a trigger species for the Chimalapas site (a larger version of the 2005 Chimalapas site).

Craugastor silvicola (EN) – to our knowledge only three specimens of *C. silvicola* have been collected. The first two of these were obtained by L. C. Binford on 9 April 1964 from 12 miles NNE of Zanatepec, Oaxaca at 1500 m. It is from one of these specimens that Lynch (1967) described the species, and the 2005 AZE site was based on this single location.

HerpNET (2009) listed a record of *C. silvicola* from Chalchijapa, Santa María Chimalapa, Oaxaca, which is housed in the UNAM collection. The specimen was collected by Mario Mancilla Moreno in 1993 and represents a significant range

Fig. IV-10. *Craugastor silvicola* from near the town of Doctor Rodulfo Figueroa on 16 May 2008. Photos courtesy of Antonio Muñoz.

extension for the species (MZFC-Herp 13396-1[19]). Our discovery of *C. silvicola* next to Cerro Baúl also extends the known range of the species, but to a much lesser extent. We found it just outside the town of Doctor Rodulfo Figueroa along a stream where the forest was a mix of conifer and broadleaf (Figures IV-9 & IV-10). For more about Cerro Baúl and Doctor Rodulfo Figueroa, see our description of the Chimalapas AZE site page 181.

Craugastor silvicola should be reassessed by IUCN.[20] The known EOO is now large and suggests that the listing of EN might be overly cautious when using the current subcriteria, B1ab(iii). Zanatepec (like Cerro Baúl) lies on the edge of Chimalapas. The additional records from Chimalapas might tempt the reader to conclude that because we know so little of this region and it is often held up as being largely intact, we are safe to assume that *C. silvicola* is not in danger of extinction. Indeed this might be the case, but Antonio Muñoz (pers. comm.) cautions that in Chimalapas one sees little forest that is truly mixed conifer/broadleaf occurring along streams. In other words, he believes the species could be present in restricted micro environments, which would give it a patchy, and not necessarily secure,

[19] As of 26 May 2014, this specimen record no longer appears on HerpNET. It is still listed (as *Eleutherodactylus silvicola*, MZFC 13396) by REMIB, but all information about it is restricted.

[20] It is a small point, but the current listing of EN is not supported by the data contained in the Red List account by Santo-Barrera and Canseco-Márquez (2004f). The EN listing is based in part on the species having an EOO that is less than 5,000 km^2 but larger than 100 km^2. This is strange because the Red List account only has information about two specimens from the type locality, which would certainly be less than 100 km^2. Thus, the current listing should have been CR if the same subcriteria were used. In any case, discussion of the validity of the current listing from the information contained in the Red List account becomes moot with the information we provide, and a reassessment is recommended.

existence in Chimalapas. Finally, although Chimalapas is amazingly wild compared to most of southern Mexico, it is changing. The susceptibility of *C. silvicola* to fire, which in 1998 devastated the hillsides near where we found the species, or to chytridiomycosis would need to be weighed by experts before an accurate assessment could be made.

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V: ADDITIONAL MATERIAL

Recommendations Regarding Chytridiomycosis

Our report has stressed the importance of conserving species at the site scale. We believe that working with communities and government entities to ensure that habitat for species remains is essential to that end. Often this will mean protecting forests from logging and agricultural expansion, improved water management, and introducing climate adaptation strategies that reduce the likelihood of catastrophic fire. Although these steps will be necessary in many cases, they are unlikely to be sufficient for amphibians in southern Mexico.

Chytridiomycosis is a major threat to amphibians (see page 35). The disease continues to move into new areas and impact the places where it has become enzootic. The disease recently arrived to Manu National Park, Peru, which holds the record for the protected area with the most species-rich herpetofauna (Catenazzi *et al.* 2011, 2013). *Bd* has also just been reported from Madagascar (Kolby 2014), an island with an extremely diverse and unique amphibian fauna. In places like Mexico chytridiomycosis exacts a heavy toll on amphibians. Many species have not been seen in over a decade and could be extinct. Even with this backdrop, there are reasons to be optimistic. Long missing amphibian species are being rediscovered, both globally and within Mexico. In some parts of the world, susceptible species are not only persisting years after *Bd*'s arrival but are increasing their numbers and returning to areas from where they had been extirpated. Reintroductions of susceptible species have begun and the results hold promise. Finally, scientists are beginning to understand the disease and there are now research leads that could result in a suite of informed management practices.

The first signs of encouragement come from the fact that highly threatened amphibians are increasingly being rediscovered (Moore 2014). In terms of conservation outcomes, field expeditions by researchers from museums, universities, conservation organizations, and zoos are highly cost-effective and worthy of more financial support. Programs dedicated to species rediscovery such as the Zoological Society of London's EDGE program, the lost frog campaign by IUCN's Amphibian Specialist Group (ASG), as well as teams led by S. D. Biju of University of Delhi in India and L. J. M. Wickramasinghe in Sri Lanka, have been especially productive.[1] Not all of the rediscovered species disappeared (i.e., had their historical numbers greatly reduced such that they could not be found) because of chytridiomycosis, but many of them did. The inspiring message of species rediscovery has resonated with people in many parts of the world (as seen by the cover story of *The Economist* 2011 about amphibian rediscoveries in India). In Mexico, species are being rediscovered in a variety of ways that range from short field trips seeking specific species (Rovito

[1] For more on each of these see: EDGE (http://www.edgeofexistence.org/index.php), lost frog campaign (http://www.amphibians.org/lostfrogs/), Biju (e.g., Biju *et al.* 2011) and Wickramasinghe (e.g., Wickramasinghe *et al.* 2013).

2010; Delia *et al.* 2013) to exhaustive systematic surveys (Sandoval-Comte *et al.* 2012; Sunny *et al.* 2014). There are also many unusual rediscovery stories in Mexico. For instance, when Mendelson *et al.* (2012) named *Incilius aurarius* from Chiapas, they noted that it had likely disappeared from the type locality (which may have been cleared), but that the species had just been refound at another locality; thus, *I. aurarius* was rediscovered even before it was formally described. In our region, we have seen four CR (PE) species rediscovered: *Craugastor polymniae* (Rovito 2009; see page 118), *Plectrohyla hazelae* (Heimes & Aguilar 2011; see page 107), *P. thorectes* (Delia *et al.* 2013), and *P. ephemera* (this report, see page 213) (see Appendix 2 page 306 for a complete list of Mexico's CR (PE) species).[2] *Plectrohyla cembra* was also rediscovered (Mendelson & Canseco-Márquez 2002), but from an earlier collection, and it was subsequently classified as CR (PE) (Santos-Barrera *et al.* 2006). Of course, even though species thought to be extinct are being found, there is no room for complacency. Rediscovered populations tend to be very small and prone to permanent disappearance without concerted efforts to safeguard habitat and manage the species (Scheffers *et al.* 2011).

Another reason for some optimism in the face of chytridiomycosis is that there is now unequivocal evidence of populations of susceptible species that are increasing in size and/or expanding in range despite the presence of *Bd*. Until recently, studies of amphibians following an epidemic (so called "post wave" amphibians) depicted them as either being wiped out by *Bd*, hanging on at low levels, or tolerating the pathogen such that it had little effect. There were a few mentions in the literature of population increase or recovery following *Bd*, but these involved just two species and were not rigorously documented. Hale *et al.* (2005) described a site in northeastern Sonora, Arroyo La Colonia, where a dead specimen of *Lithobates tarahumarae* (VU) was collected in 1982 and subsequently shown to have died from chytridiomycosis. In 1985, the site was surveyed and not a single ranid frog was found. When Arroyo La Colonia was re-surveyed in 1999, *L. tarahumarae* were plentiful: "we believe this population declined or was extirpated, but rebounded or was recolonized, over a period of 17 years" (Hale *et al.* 2005:410). The other example is that of *Litoria genimaculata* (LC) in Queensland, Australia that declined from 1990–1994 due to chytridiomycosis, but has since recovered and is common (Woodhams & Alford 2005). McDonald *et al.* (2005:114) stated that this species "has increased to pre-decline numbers", and, almost identically, Richards and Alford (2005:229) claimed the "*L. genimaculata* population subsequently recovered to pre-'decline' levels." These reports of recovery are encouraging and might have

[2] We note that there is no standard measure for a species to be considered "lost." We used CR (PE) as a short cut. Certainly, rediscoveries such as the finding of San Cristóbal Shrew (*Sorex stizodon*) in Chiapas after more than 100 years are equally exciting (Naranjo & Espinoza Medinilla 2001) (see "AZE 2010 Site: Huitepec - Los Alcanfores" on page 244). For an expanded discussion of this point, see Scheffers *et al.* (2011).

been the result of real population gains, but they could neither account for a host of potential detection biases nor distinguish the possibility of recolonization (although this in itself would be something). The recent evidence of population increases by *Alytes obstetricans* (LC) in Switzerland (Tobler *et al.* 2012) and *Mixophyes fleayi* (EN) in Australia (Newell *et al.* 2013), as well as an increase in both numbers and reclaimed territory by *Litoria verreauxii* (LC) in Australia (Scheele *et al.* 2014a) are testament to the potential for recovery in some species. Furthermore, there are encouraging signs coming from the reintroduction of Kihansi Spray Toad (*Nectophrynoides asperginis* EW) to Tanzania,[3] the fact that four reintroductions of *A. obstetricans* in Switzerland appear to have succeeded (B. Schmidt, pers. comm.), and the apparently successful reintroduction of *Litoria spenceri* (CR) to Kosciuszko National Park in New South Wales, Australia (Marris 2008; Cubby 2011).

We concluded our introduction to chytridiomycosis with a list of possible reasons why individuals and populations of susceptible species persist despite the presence of *Bd* (page 49). We believe that investigations into those hypotheses are likely to result in principles that inform management practices. In this appendix, we lay out more specific recommendations for research and action that focuses on chytridiomycosis to benefit amphibian conservation in southern Mexico.[4] For reviews of emerging techniques that are being developed to fight the disease, see Woodhams *et al.* (2011) and Scheele *et al.* (2014b).

1) Protect as much montane forest as possible

The hopeful signs we are seeing in relation to amphibians are predicated on the existence of habit. Few of the missing species in our region are likely to be rediscovered in non-forested habitats and none will exhibit signs of recovery without intact forests. Scheele *et al.* (2014a:86) made this case stating that their own research into recovery provides "an impetus for the protection of historical, but currently unoccupied amphibian habitats and highlights the importance of maintaining high quality habitat to help species survive novel shocks such as pandemic diseases."

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[3] Although this is a species that was extirpated from the wild because of the construction of a dam and not the arrival of *Bd*, the species has subsequently proven to be highly susceptible to the pathogen, and its reintroduction was considered by many to be impossible until chytridiomycosis could be mitigated. On 26 June 2012, excess individuals of *N. asperginis* were reintroduced anyway.

[4] For recommendations concerning other threats to amphibians, we refer the reader to the Amphibian Conservation Action Plan (ACAP) (Gascon *et al.* 2007); it remains the best single source. The ACAP is the proceedings of the IUCN/SSC Amphibian Conservation Summit (see Mendelson *et al.* 2006) and can be freely accessed at: http://www.amphibians.org/publications/amphibian-conservation-action-plan/. ACAP, however, offers few recommendations specific to chytridiomycosis.

2) View captive breeding as part of a continuum that begins with selecting amphibians for *ex situ* conservation and results in the recovery of wild populations

If we ultimately want highly threatened species to thrive in their native habitats, then it follows that we need both habitats (recommendation 1) and amphibians to occupy them. Captive breeding is essential to this second point, thus serving as a means of complementing *in situ* efforts. Through captive breeding, we are buying time for species that could otherwise be wiped out as well as bolstering population numbers for their eventual release. Unfortunately, practitioners sometimes regard the success of locating missing species and/or breeding them in captivity as the end goal. The ultimate goal should be the recovery of threatened species, and to accomplish this we suggest adopting a more process-oriented mindset with a greater emphasis on experimental reintroductions accompanied by monitoring and an open exchange of results.

Captive breeding could prove useful for a number of threatened amphibian species.[5] Although some of these can be readily obtained in the wild, other candidates for captive breeding will result from rediscoveries. Planning for the acquisition, or even the possible acquisition, of threatened species is the beginning of the process and it should be closely linked to captive breeding. This will require more collaboration between field researchers and experts in *ex situ* conservation. While the onus for such collaboration resides equally with both groups, the fact that zoos increasingly recognize the need to work collaboratively amongst themselves might open an avenue for working more closely with others in the field. Collaboration in the zoo context is important in terms of managing captive individuals of a species at multiple institutions as a single metapopulation. Risk should be spread across institutions and further efforts could include jointly targeting species for acquisition (Conway 2011).

Zoos have made great strides in terms of ramping up amphibian collections during the amphibian crisis, but amphibians still lag behind other groups and far behind what is required given the magnitude of the problem (Conde *et al.* 2011a). For instance, zoos still hold few threatened amphibian species relative to other terrestrial vertebrates (Conde *et al.* 2011b), and they are more likely to consist of smaller population sizes than are viable (Conde *et al.* 2013). This is difficult to explain given that authors with different views towards captive breeding (e.g., those who believe it can play only a small part in overall conservation and those who believe it is central to conservation) unite around the idea that zoos ought to house more species of amphibians (Bowkett 2009; Balmford *et al.* 2011; Conde *et al.* 2011a). The insufficient numbers of individuals for a given species in captivity is also hard to explain

[5] Also cryobanking continues to make advances that will benefit captive breeding and might become another useful form of assurance (reviewed by Kouba *et al.* 2013).

because many amphibians reproduce proficiently when in captivity. There are, of course, large amphibian groups that are notoriously difficult to breed (e.g., plethodontid salamanders) and many individual species for which successful husbandry remains a mystery (see Mendelson 2011 for a tragic account of one such species).

Nonetheless, amphibians often breed so well in captivity that dealing with surplus animals can be a challenge. Amphibians have several traits that make them generally good candidates for captive breeding and ultimately for reintroduction: small size of individuals (meaning many can be housed in a small area for lower cost than for larger animals), little or no behavioral problems over multiple generations (wild birds and mammals in contrast often have learned behaviors that erode when generations are captively bred), and high fecundity that can result in large numbers (Bloxam & Tonge 1995; Browne *et al.* 2011). This last trait means that when captive breeding is successful it can quickly outstrip capacity to house all of the offspring. We suggest that reintroduction plans be developed once captive individuals begin to breed successfully. At present, most captive breeding programs for highly threatened amphibians do not have a plan for reintroduction (or even an explicit goal of what the program hopes to accomplish), and many institutions routinely euthanize individuals in excess of what the facility can hold (C. Gascon and J. García Moreno, pers. comm.). Amphibian Ark (AArk) has a program to help ACAP partners who have excess individuals by making them available to other partners for research (Zippel *et al.* 2011). It has also been suggested that some rare species should become fixtures in laboratory studies such that more institutions will have an interest in housing them (Zippel & Mendelson 2008; Zippel *et al.* 2011). We think the existence of excess individuals provides an excellent opportunity for a range of experimental trials which could increase our understanding of what reintroduction techniques work with respect to amphibians that have been devastated by chytridiomycosis.

Reintroduction of captive-bred species in a world of chytridiomycosis is essential, yet there is little agreement as to whether it is possible or even ethical to attempt reintroductions at present. There is broad agreement on certain things, such as the fact that animals must be rigorously tested and proven disease free prior to release (Cunningham 1996; Walker *et al.* 2008; Pessier & Mendelson 2010). However, the procedures to follow that have the best chances of achieving self-sustaining populations are much less certain. Standard reintroduction guidelines demand that the initial threat be removed prior to reintroduction, even for excess individuals. The Association of Zoos and Aquariums (AZA 1992) states, "reintroduction should not be used solely to dispose of animals surplus to a captive population," and IUCN (1987) states, "re-introductions should only take place where the original causes of extinction have been removed." Increasingly, such guidelines allow for the original cause of decline to be reduced "to a sufficient level" (IUCN 1998), and,

most recently, that "there should generally be strong evidence that the threat(s) that caused any previous extinction have been correctly identified and removed or sufficiently reduced" (IUCN/SSC 2013:4). AArk believes that "organisms can only be released after threats are understood and mitigated" (Zippel *et al.* 2011:345). The question is whether chytridiomycosis is understood. And if it cannot be removed, can it at least be mitigated and reduced to a sufficient level?

One approach to answering these questions is by experimentation and the sharing of information from reintroduction trials (both successes and failures), but reintroductions are risky. Even species such as European Starling (*Sturnus vulgaris* LC), a bird introduced to New York in 1890–91 that is now the fifth most common bird in North America (Sauer *et al.* 2014), failed to take hold after numerous attempts at introduction (Cabe 1993). Successfully reintroducing extremely rare amphibians will be much more challenging, and failed attempts are to be expected. The two most recent reviews of amphibian reintroduction programs have shown them to be successful in the majority of cases, which is remarkable, but they are still risky ventures (Griffiths & Pavajeau 2008; Germano & Bishop 2009). The additional threat of chytridiomycosis complicates matters, but it should not prevent us from exploring what is possible.[6]

There are a number of variables related to reintroduction that can be manipulated. For instance, are there times of year, certain life stages, different densities, or a number of repeat releases that produce better outcomes than a single release? Trial reintroductions could answer these basics, but they could also determine whether or not active interventions help amphibians reestablish. Thus, are outcomes better when we boost the ability of released animals to cope with *Bd* (e.g., bioaugmentation, repeated exposure to dead *Bd*, breeding tolerance and/or resistance)? Are outcomes improved if and when we reduce *Bd* numbers at the reintroduction site? Sorting out best practices requires the practitioners to be systematic in their release designs. Adaptive management as developed by Holling (1978) and Walters (1986) is one possible approach.

Reintroductions lend themselves to an active adaptive management framework where not just what works is repeated, but where each activity is an experiment

[6] Unfortunately, such prevention does occur. For example, the reintroduction efforts mentioned above for *A. obstetricans* were halted once *Bd* was detected (B. Schmidt, pers. comm.). Similarly, *A. muletensis* (VU) reintroductions to Mallorca were stopped when *Bd* was detected. *A. muletensis* was held in captivity before chytridiomycosis was viewed as a threat (like *N. asperginis*), and reintroductions of the species took place prior to it being recognized as an active threat in Mallorca (indeed, it was the reintroduction of the species that brought the disease to the island). Still, it is worth noting that despite the presence of *Bd* at *A. muletensis* reintroduction sites, "at least 10 populations have been successfully reintroduced" (Serra *et al.* 2009).

designed to increase practical knowledge (Armstrong & Seddon 2007; Seddon *et al.* 2007). We are well aware of the limitations of adaptive management. Literature reviews consistently show that despite numerous full length articles arguing for its use in natural resource management and conservation, actual use of adaptive management is rare (McFadden *et al.* 2011; Rist *et al.* 2013; Westgate *et al.* 2013). Allen and Gunderson (2011) summarized the reasons for this discrepancy. In addition to many practical difficulties (e.g., cost, willingness to try something new), adaptive management is only useful in circumstances where an acute lack of knowledge coincides with a controllable setting that allows for experimental design (Allen *et al.* 2011; Allen & Gunderson 2011). McDonald-Madden *et al.* (2010) produced a decision tree to identify suitable situations for adaptive management with these same considerations, but even in the resulting adaptive-management-recommended atmosphere the manipulations performed will usually have to be severe to show a meaningful result within a project's limited time frame (Sutherland 2006). Amphibian reintroductions fall within the narrow space where adaptive management is not only appropriate, but useful. For success to be achieved we would expect many individuals to be lost (i.e., severe intervention), but the large numbers of amphibian individuals available for reintroduction make this possible. Moreover, there are myriad reintroduction variables that require investigation (i.e., acute lack of knowledge) and these can easily be adjusted experimentally (i.e., controllable setting).

Two additional components can make adaptive management frameworks more effective. First, results must be carefully monitored. There is no point in setting up an experimental design if the outcomes are not tracked. Second, reintroductions will benefit greatly from an exchange of information among practitioners about what works and what does not (Griffith *et al.* 1989). Zoos have had tremendous success when sharing records about captive breeding itself (Sutherland *et al.* 2004), and recently a website for exchanging information about treatment of captive *Bd* positive amphibians has been recommended (Woodhams *et al.* 2012). AArk has started the process with standardized forms/questionnaires that are filled out by those conducting amphibian reintroductions. These are analogous, though not yet as thorough, as the Avian Reintroduction and Translocation Database (http://www.lpzoo.org/ARTD). Equally important will be the adoption of a minimum set of standards for what should be monitored and reported to increase the efficacy of reintroduction efforts. Standards have been proposed for birds and these could readily be applied to amphibians with little modification (Sutherland *et al.* 2010). There are issues uniquely related to amphibian reintroductions. For example, the possible range of mitigation measures for *Bd* that were used (or not used) should be documented in a consistent manner, but otherwise we agree with Sutherland *et al.* (2010) that having standards of what information is collected and exchanged would be similar to those put forward for birds.

Practitioners should, on occasion, attempt things that are counterintuitive and be on the lookout for useful patterns and practices. As an example, we suspect that some of the rules of thumb for reintroductions could be either ineffective or even counterproductive for amphibians in relation to chytridiomycosis. Two common reintroduction tenets are that 1) the more animals you release, the more likely they will be successful at breeding and taking hold, and 2) you should reintroduce the animals into the best remaining habitat within the core of the species' historical range (see Griffith *et al.* 1989). Both of these points make sense and the first is backed by data (Germano & Bishop 2009). However, with what we know of the density dependence of the disease, it could be more effective to release a series of small numbers of individuals so that *Bd* does not rapidly overwhelm the population. On the second point, reintroductions tend to favor sites where the species last existed because the habitat is often in better condition. However, if a species has contracted greatly in range (to the point of disappearing) because of chytrid fungus, it might be prudent to reintroduce it to the first locality where it disappeared rather than the last, potentially allowing more time for *Bd* to either die out or be reduced in density. These are examples of why careful thought as to how to reintroduce these species is required and that conventional wisdom might be wrong. Similarly, Germano & Bishop (2009:12) found that success of amphibian reintroductions was not correlated to the life stage of the released animals; although these authors also noted that "little—if any—experimental work" has been conducted in relation to the reintroduction of different life stages. Thus, because life stages vary in their ability to withstand chytrid fungus, perhaps we will find that certain life stages increase the success rate when *Bd* is a factor.

Overall, we believe that captive breeding has great potential for amphibian AZE species, even *in situ*. In practice, the lines between traditional *in situ* and *ex situ* conservation and the reintroduction that connects the two are often blurred and are likely to become increasingly blurred in the future (Pritchard *et al.* 2011; Redford *et al.* 2012). For example, restocking programs have aspects of both *in situ* and *ex situ* conservation, and soft releases or intense management at a site can be difficult to distinguish from captivity especially when enclosures are large. In some circumstances, it might prove useful to rotate individuals between captive and wild populations on an ongoing basis. Thus, restocking would occur repeatedly in both directions to ensure genetic variation of the assurance population while supplementing the wild population. Even the physical distance between *in situ* and *ex situ* management could become (or has in some cases) diminished as many practitioners argue that the best captive breeding results occur when the species is held near the eventual site of release. We mention ways in which the demarcation between *in situ* and *ex situ* may be (or become) less noticeable because it highlights the fact that captive breeding practitioners' expertise might have wider application. Zoo scientists are experts at managing small populations—like those that inhabit AZE

sites, therefore these experts have insights and solutions to offer when dealing with small-population problems. It is also possible that something like the accreditation system that zoos developed might be of use when it comes to ensuring sound management at these sites (see Conway 2011).

3) Test reduction of *Bd* levels before a lethal threshold is reached

The density dependence of *Bd* growth and transmission within amphibian populations implies that one way to reduce *Bd* below lethal thresholds is by limiting the numbers of amphibians. In aquatic systems, this could mean temporarily removing tadpoles that might be serving as disease reservoirs (Woodhams & Alford 2005; Briggs *et al.* 2010).[7] We mentioned this intervention above as a possible variable to experimentally manipulate in relation to reintroduction, though it could have benefits for wild populations as well. Other known, or strongly suspected, reservoirs should be considered for removal or reduction on a case by case basis. When a known wave of *Bd* is advancing, the temporary, or possibly long-term, capture of individuals from populations that are of concern should also be considered.[8]

Anti-fungal agents have been suggested as an extreme intervention that could be warranted at a small scale to reduce *Bd* to benefit highly threatened species (Briggs *et al.* 2010; Vredenburg *et al.* 2010; Woodhams *et al.* 2011). We agree, but only as a last resort given what is currently known about these chemicals. The application of anti-fungal agents to infected amphibians often results in adverse side effects (Woodhams *et al.* 2012) and could have unintended consequences within natural settings. There is a need to identify better techniques for curing *Bd* in captive or rescue situations (Berger *et al.* 2010), and perhaps such information could then inform management options at a site. Still, despite numerous failures in relation to anti-fungal remedies, new laboratory trials of nikkomycin Z are promising and supported by recent insights into *Bd* (Fites *et al.* 2013; Holden *et al.* 2014).

Other physical manipulations to reduce *Bd* in the environment have been tried or suggested in the literature. For instance, warm water has been correlated

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[7] Capturing and raising tadpoles within a site could be done very inexpensively. We know of communities who would readily help in such efforts and tadpole tanks could also serve a useful educational role. We do not know how well such a program would work, but it is something worth testing. Scheele *et al.* (2014b) noted that the Honduras Amphibian Rescue and Conservation Center (HARCC) is in the process of removing tadpoles from a system so that they can be reared past the time at which they are most susceptible to chytridiomycosis. Thus, HARCC is hoping that the reared tadpoles can augment the breeding population; we suggest that this plan might also benefit wild frogs by removing disease reservoirs.

[8] This approach was taken in Panama by multiple institutions and has resulted in several species existing in captivity that would likely have otherwise gone extinct (Gagliardo *et al.* 2008; Marris 2008; Stone 2013).

with lower levels of *Bd*. Scheele *et al.* (2014b) discussed the removal of branches along a stream in order to raise water temperature and to provide more basking sites for frogs, thus reducing *Bd* in the environment and facilitating behaviors that reduce an individual's pathogen load. Extreme management interventions should be considered/tested for discreet areas of high priority. Scheele *et al.* (2014b) suggested testing artificial heat sources in areas where mechanical modifications (i.e., branch removal) is infeasible. Other extreme management techniques include the temporary draining of ponds (see discussion of Bosch in Lubick 2010) and the enhancement or introduction of microscopic *Bd* predators to the environment. Humans have manipulated aquafauna in water systems for a long time and there are likely to be ways to manage them for reduced *Bd* levels (Schmeller *et al.* 2014).

How to reduce *Bd* loads in the environment to manage better outcomes for terrestrial salamanders and direct-developing frogs is a crucial question that we have not seen anyone address and one for which we have no answer.

4) Prevent the spread of *Bd*

There is often mention of spraying boots and tires with a 10% bleach solution before conducting research at field sites and when moving between sites and/or between major habitats within a site (Daszak *et al.* 2007). The importance of this measure is based on the assumption that people can introduce *Bd* into areas. There is little direct evidence supporting the introduction of *Bd* that does not involve the transport of amphibians, and we know that some herpetologists are skeptical of spraying as a preventative measure. We are, however, strong advocates for spraying. The monetary cost of spraying is insignificant as is the cost in terms of inconvenience. Even if the possibility of introducing *Bd* to a new environment were remote (and we see no evidence that this is the case), the devastation that could ensue makes spraying a bargain at any price. It is important to remember that even where *Bd* occurs, *Bd* loads should be reduced not increased (to reduce transmission and spread), and that different strains of the fungus exist. *Bd* isolates obtained from different parts of the world, for instance, have been shown to vary in terms of their growth in relation to temperature and pH (Piotrowski *et al.* 2004), and they demonstrate differences in terms of virulence (Berger *et al.* 2005; Retallick & Miera 2007; Fisher *et al.* 2009; Farrer *et al.* 2011). For more about ways to prevent the spread of *Bd* see Hyatt *et al.* (2007), Young *et al.* (2007), and Phillott *et al.* (2010). These measures are particularly important with respect to remaining pockets where the fungus does not occur.

Universities and museums should adopt decontamination protocols for all of their work—not just herpetologists, and not just because of *Bd*, but to reduce

the risk of introducing the next pathogen or invasive species. The discovery of another pathogen, *Batrachochytrium salamandrivorans*, that is capable of causing chytridiomycosis and which has not been detected in the New World supports this argument (Martel *et al.* 2013, 2014; Stokstad 2014). Governments (from community to federal) should require commitments to such protocols as prerequisites for research and collection permits. Foundations and other non-profit institutions that support field research should likewise insist on responsible behavior.

Standards should be set for the transport of amphibians that are stringent and enforced—as they are for livestock. Species that are commonly traded either as pets or for consumption are carriers of *Bd* (Weldon *et al.* 2004; Fisher & Garner 2007; Smith *et al.* 2009; Schloegel *et al.* 2009, 2010, 2012). There must be assurance that the animals themselves as well as the containers and associated materials (i.e., water, aquaria substrate, and waste) are free of *Bd*. This will require standards for care and transport, testing, possibly quarantine measures, and protocols to reduce spread if and when releases occur (for specific recommendations see Fisher & Garner 2007; Smith *et al.* 2009; Schloegel *et al.* 2009, 2010; Gratwicke *et al.* 2010). In addition, there needs to be a global system for tracking the trade in amphibians and disease surveillance programs to detect disease prevalence within trade (Schloegel *et al.* 2010).

5) More research on probiotic bioaugmentation and *Bd* immunosuppression

Bletz *et al.* (2013) conducted a detailed review of the potential of using probiotics to protect amphibians from *Bd* before it arrives to a new area or for aiding the reintroduction of captive animals that might otherwise be eliminated by chytridiomycosis. These authors outline sampling strategies and filtering protocols to identify beneficial microbes that the host will accept, can use at different life stages, and retain under variable conditions. They also stress that it is important for local microbes to be used in order to reduce the chances of creating unintended consequences for the environment. To date, little of the research on antifungal skin microbes has occurred in relation to tropical species. Fortunately, this is starting to change (Becker *et al.* 2011; Flechas *et al.* 2012; Küng *et al.* 2014).

There are numerous questions regarding bioaugmentation. Most importantly, will it work under field conditions that are not too onerous from a management or cost perspective? This cannot be answered without further trials. There are also questions about specific aspects of bioaugmentation. For instance, to what extent is there herd immunity? Specifically, how much of an amphibian population needs to be inoculated for adequate resistance/tolerance? How long can anti-*Bd* bacteria introduced to an amphibian remain (Belden & Harris 2007)?

What techniques are best for the application and maintenance of bacteria? Can one introduce probiotics to the environment (as has been done successfully in agriculture) such that multiple amphibian species benefit (see Muletz *et al.* 2012; Bletz *et al.* 2013)? Is introducing a single microbe or a mix of multiple microbes best? Also, new techniques to assess bacterial composition and load could be very beneficial (e.g., Xia *et al.* 2011). At present, only a small fraction of bacteria can be cultured and the presence of anti-*Bd* bacteria is determined in a yes/no fashion, which gives a limited view to their world. We also need to understand more about the mechanisms by which certain bacteria and their metabolites deter *Bd* and the interactions between microbes.

Transcriptional investigations into the genomic response of amphibians to *Bd* exposure produced several hypotheses as to why many species were not able to mount a sufficient immune response to the pathogen. One of these hypotheses was that *Bd* was suppressing host immune response in some way. This appeared to be the case when *Xenopus tropicalis* (LC) showed decreased gene expression after exposure to *Bd* compared to non-exposed individuals (Ribas *et al.* 2009; Rosenblum *et al.* 2009). More recently, there is evidence that *Bd* inhibits lymphocyte-mediated swelling *in vitro* (Fites *et al.* 2013) and that genes which might lead to an immune response to *Bd* can be activated and subsequently suppressed (Ellison *et al.* 2014). *In vivo*, experiments indicate that *Bd* inhibits immunity (Young *et al.* 2014; Fites *et al.* 2014). Thus, it is likely that some species may be better at defending themselves against *Bd* not because they inherently have more robust immune systems, but because the immune suppressive factors emitted by *Bd* are less effective on them.

Research into immunosuppression by *Bd* has many practical applications for conservation. For example, it has led directly to nikkomycin Z being a possible way to decrease *Bd* loads (see above). Another avenue of this research has been to find new ways to expose captive amphibians to *Bd* so that they are more prepared to defend against the pathogen in the wild. Repeated exposure to live *Bd* and to dead *Bd* increased lymphocyte abundance and proliferation in amphibians; amphibians were also able to learn to avoid the presence of *Bd* behaviorally with repeat exposure (McMahon *et al.* 2014). These findings suggest that the immunosuppression of *Bd* can be overcome and they hold promise for improving reintroduction efforts for susceptible species. McMahon *et al.* (2014:226) further suggest that:

> "additional research is necessary to quantify the efficacy of releasing dead *Bd* into water bodies to protect amphibians and the non-target effects of these releases"

And that,

> "the efficacy of this management option will depend on several factors, such as whether *Bd*-naive larval amphibians can also acquire immunity, the role of biotic and abiotic reservoirs in maintaining *Bd*, and the extent and magnitude of variation in acquired resistance among amphibian species" (pp.226–227)

The program for further investigation laid out by McMahon *et al.* (2014) is certainly a priority, but many similar questions to those concerning probiotic bioaugmentation are here as well. For instance, how many repeat exposures are required, how long does the heightened lymphocyte abundance last, what proportion of the population would need to be exposed, are there best practices for environmental application, and are unintended consequences possible? Finally, with both captive amphibians prior to reintroduction and releases to the environment, the trade-offs or complementary approaches vis-à-vis probiotics should be investigated experimentally.

6) Research the ecology of *Bd*

Many basic questions remain about the ecology of *Bd* and much of what is known should be reassessed given recent developments—in particular, the identification of separate *Bd* lineages (Farrer *et al.* 2011).

Two of the most vexing, yet fundamental, questions related to the ecology of *Bd* are: 1) Why does the virulence of chytridiomycosis change so dramatically with elevation? and 2) How does *Bd* move across the landscape? The impact of chytridiomycosis is much greater in montane settings relative to lowlands. This trend is typically attributed to more favorable temperatures at higher elevations for *Bd* growth. At other times authors assume that a greater susceptibility of montane species to the disease exists because of genetic differences between hosts at different elevations or a lowered immune response compared to amphibians at higher elevations. These possibilities have not been tested relative to each other in the field and there are alternative hypotheses that are also worth consideration. Muths *et al.* (2011), for example, hypothesized that Boreal Toads (*Anaxyrus boreas* NT) were more severely impacted by chytridiomycosis at high elevations because of the lower productivity of the environment and because of the shorter window of time in which the host has to reproduce. Thus, when *Bd* infects Boreal Toads at lower elevations, the longer, more productive growing season allows for greater flexibility in terms of modes of recruitment. We also think it is worth considering the possibility that *Bd* encounters fewer predatory microbes at higher elevations or that host skin contains fewer anti-*Bd* constituents, thus *Bd*'s impact on amphibians at higher

elevation would be due to its release from these constraints.

Little is known about how *Bd* moves across the landscape and how it is transmitted to individuals in natural settings. Vredenburg *et al.* (2010) showed that chytridiomycosis moved in a predictable fashion from one lake to the next, which would argue against avian carries since these would presumably skip over adjacent lakes. Garmyn *et al.* (2012) found evidence that waterfowl could move *Bd* DNA from one place to another; however, a key question is whether these animals can transport viable *Bd* zoospores. Reptiles (Kilburn *et al.* 2011) and crayfish (McMahon *et al.* 2013) are also potential non-amphibian vectors for the disease. It is quite likely that *Bd* uses different means to move across landscapes in different environments. For this reason, more work identifying vectors, disease reservoirs, and modes of *Bd* transmission within a given region or site could prove useful in designing ways to manage for the disease.

The recent finding by Farrer *et al.* (2011) that separate *Bd* lineages have differing levels of pathogenesis implies that a number of previous experiments should be replicated to ensure results are robust to other differences that may exist between lineages. For instance, Piotrowski *et al.* (2004) is often cited for information concerning the optimal temperature for *Bd* growth, yet their findings apply to just one *Bd* lineage.[9] Similarly, studies concerning the ability of *Bd* to withstand various chemical treatments as well as any aspect of ecology one mentions may have only been tested for a single lineage. Therefore, more lineage-specific studies should be conducted.

7) Research the spread and extent of *Bd*

Museum specimens in Mexico and foreign institutions with material from Mexico should be thoroughly and systematically sampled for the presence of chytrid fungus (continuing the work of Cheng *et al.* 2011). Studies within Mexico on amphibians should be encouraged to add *Bd*/chytridiomycosis surveillance as a component of their work. More field studies aimed at determining the prevalence of the disease and pathogen load over time and space should be performed along with its demographic implications for amphibians. There is a sense that it is uncertain whether or not chytridiomycosis has been (or is) a serious problem within Mexico because few studies of the disease have been conducted here (Ochoa-Ochoa *et al.* 2009; Frías-Alvarez *et al*. 2010). In fact, a major review of the status of amphibians in Mexico failed to mention it (Wilson *et al.* 2013). We have argued that chytridiomycosis is an extreme threat to amphibians in southern Mexico, but more evidence (even if it is not

[9] Also, the growth with temperature results from Piotrowski *et al.* (2004) apply to growth *in vitro*, which might not resemble growth in a natural setting (for example Raffel *et al.* 2013 found that optimal growth of *Bd* on actual amphibian skin differs from *in vitro*).

before, during, and after a wave) could be useful for conveying the importance of the disease and for understanding dynamics related to its spread, persistence, impact, and for the identification of reservoir species.

8) Researchers (especially concerned with the etiology and spread of *Bd*) should proceed as though the standard assay for detecting *Bd* is able to detect only a portion of the pathogens that can cause chytridiomycosis

PCR has been a tremendously useful tool to investigate the presence of *Bd* (e.g., Annis *et al.* 2004), and, with real time quantitative PCR, loads of *Bd* equivalents can be measured on individual host amphibians (Boyle *et al.* 2004). However, the increased recognition of deeper evolutionary lines within *Bd* (Farrer *et al.* 2011; Rosenblum *et al.* 2013) and the formal description of another causative agent for chytridiomycosis, *B. salamandrivorans* (Martel *et al.* 2013), cause us to wonder about what we are missing with standard PCR detection regiments. For instance, are the truly enigmatic declines (*sensu* Caruso & Lips 2013) the result of a new threat (or combination thereof) or could they be a strain of *Bd* or another close relative that cannot be detected by PCR?

In addition, *Bd* detection using PCR returns a substantial number of false negatives even when targeting known lineages (meaning that prevalence of the pathogen is underestimated). Langhammer *et al.* (2013), for instance, found that low-level infections can go undetected for a surprisingly long time. Woodhams *et al.* (2012) also discussed this point. Specifically, these authors argued that the standard thresholds for field based tests of *Bd* prevalence are not appropriate for most laboratory settings where relative load might be more informative. Also, field samples can be contaminated with compounds that cause PCR inhibition (particularly the presence of humic acids) (Garland *et al.* 2010; Kosch & Summers 2013). PCR inhibition is likely to be related to certain habitats and if ignored could lead to bias when comparing levels of *Bd* prevalence between localities or taxonomic groups. That said, PCR will continue to be a valuable tool and efforts to improve and expand the suite of what it can detect are worthwhile (e.g., Garland *et al.* 2010; Blooi *et al.* 2013; Kosch & Summers 2013; Shin *et al.* 2014). Finally, several authors have noted the need to synchronize global epidemiological studies that reveal the lineage of *Bd* (e.g., Farrer *et al.* 2011) with the large-scale screening exercises that are trying to determine the extent and load of infection (e.g., Swei *et al.* 2011).

9) Investigate determinants of *Bd* pathogenesis

Venesky *et al.* (2012) argued that captive amphibians should be bred for tolerance to *Bd* rather than resistance. Tolerance is the ability of the host to withstand the pathogen, while resistance is defined as host mechanisms that actively fight the pathogen. These authors contend that breeding resistance to *Bd* could backfire

because pathogens have shorter generation times than their hosts such that, "this evolutionary lag could result in more virulent pathogens" (Venesky *et al.* 2012:588). However, increased pathogenesis is just one possible evolutionary path (May & Anderson 1983). Indeed if this increased virulence always occurred where there was a difference between host and pathogen generation time, every fecund pathogen would have overrun every higher order organism long ago. The reason this does not occur, of course, is because of the genetic variation within host populations and evolutionary potential provided to organisms that exchange gametes in the course of sexual reproduction (Ebert & Hamilton 1996). Still, *Bd* evolution appears to be rather complex and the recommendations of Venesky *et al.* (2012) are worth pursuing.

Bd reproduces asexually, producing clones, which in theory should limit its ability to evolve quickly. However, it is becoming increasing likely that *Bd*, like many other largely clonal organisms (Halkett *et al.* 2005), evolves rapidly by mechanisms that are not clonal in nature. Most laboratory studies of *Bd* use cultures of the pathogen that are grown and maintained on a nutrient substrate—often for years. Every few months these cultures are passaged, meaning they are introduced to a new substrate. Langhammer *et al.* (2013) found that cultures of *Bd* become less pathogenic over time. Farrer *et al.* (2013) studied the genome of *Bd* passaged for 40 generations. When *Bd* was exposed to an antimicrobial peptide, the *Bd* genome under study changed dramatically. Moreover the classes of genes under selection are known to be related to pathogenesis. The process of change is called aneuploidy or chromosomal copy-number variation (CCNV), which allows recombination to occur. Moreover, three different lineages of *Bd* "evolved" at different rates. The authors believe CCNV might explain *Bd*'s phenotypic variation and the wide range of hosts it can infect. There is also some evidence that *Bd* differs between habitats—possibly indicating rapid evolution to fill ecological niches (Kaiser & Pollinger 2012). Together these studies paint a picture of *Bd* as being more dynamic evolutionarily than one might expect. Knowing which *Bd* genes alter pathogenicity, why and how pathogenicity changes in culture, and the evolutionary potential of *Bd* could lead to disease interventions. It would also answer whether or not we should breed for tolerance or resistance.

From a practical point of view, the approach advocated by Venesky *et al.* (2012) makes sense to us. These authors suggested that subsets of different clutches of a captive species would be exposed to the pathogen and the remainder (i.e., the unexposed) of the clutches that died more slowly would be bred again. Repeating this procedure many times over could produce individuals that are more tolerant of *Bd*. It is hard for us, however, to see how one would know that tolerance and not resistance was being selected. Nonetheless, the approach should be tried.

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Appendix 1. Description of IUCN Red List Categories. A reproduction of box 2.1 from IUCN-SPSC (2014).

EXTINCT (EX)

A taxon is Extinct when there is no reasonable doubt that the last individual has died. A taxon is presumed Extinct when exhaustive surveys in known and/or expected habitat, at appropriate times (diurnal, seasonal, annual), throughout its historic range have failed to record an individual. Surveys should be over a time frame appropriate to the taxon's life cycles and life form.

EXTINCT IN THE WILD (EW)

A taxon is Extinct in the Wild when it is known only to survive in cultivation, in captivity or as a naturalized population (or populations) well outside the past range. A taxon is presumed Extinct in the Wild when exhaustive surveys in known and/or expected habitat, at appropriate times (diurnal, seasonal, annual), throughout its historic range have failed to record an individual. Surveys should be over a time frame appropriate to the taxon's life cycle and life form.

CRITICALLY ENDANGERED (CR)

A taxon is Critically Endangered when the best available evidence indicates that it meets any of the criteria A to E for Critically Endangered, and it is therefore considered to be facing an extremely high risk of extinction in the wild.

ENDANGERED (EN)

A taxon is Endangered when the best available evidence indicates that it meets any of the criteria A to E for Endangered, and it is therefore considered to be facing a very high risk of extinction in the wild.

VULNERABLE (VU)

A taxon is Vulnerable when the best available evidence indicates that it meets any of the criteria A to E for Vulnerable, and it is therefore considered to be facing a high risk of extinction in the wild.

NEAR THREATENED (NT)

A taxon is Near Threatened when it has been evaluated against the criteria but does not qualify for Critically Endangered, Endangered or Vulnerable now, but is close to qualifying for or is likely to qualify for a threatened category in the near future.

LEAST CONCERN (LC)

A taxon is Least Concern when it has been evaluated against the criteria and does not qualify for Critically Endangered, Endangered, Vulnerable or Near Threatened. Widespread and abundant taxa are included in this category.

DATA DEFICIENT (DD)

A taxon is Data Deficient when there is inadequate information to make a direct, or indirect, assessment of its risk of extinction based on its distribution and/or population status. A taxon in this category may be well studied, and its biology well known, but appropriate data on abundance and/or distribution are lacking. Data Deficient is therefore not a category of threat. Listing of taxa in this category indicates that more information is required and acknowledges the possibility that future research will show that threatened classification is appropriate. It is important to make positive use of whatever data are available. In many cases great care should be exercised in choosing between DD and a threatened status. If the range of a taxon is suspected to be relatively circumscribed, if a considerable period of time has elapsed since the last record of the taxon, threatened status may well be justified.

NOT EVALUATED (NE)

A taxon is Not Evaluated when it is has not yet been evaluated against the criteria.

Reference

IUCN-SPSC (IUCN Standards and Petitions Subcommittee). 2014. *Guidelines for Using the IUCN Red List Categories and Criteria. Version 11.* Available at: <http://www.iucnredlist.org/documents/RedListGuidelines.pdf>. Downloaded 31 May 2014.

Appendix 2. Table of Mexican species flagged by IUCN as Possibly Extinct. The list is from Red List version 2014.3, received 23 January 2015. Amphibians dominate with 28 out of 39 total species. This is a large list for a country. "X" marks 15 species known from Chiapas and Oaxaca. * indicates species for which we have included notes pertaining to the Possibly Extinct designation (see next page).

Phylum	Class	Order	Family	Species	Region
Arthropoda	Malacostraca	Decapoda	Cambaridae	*Cambarellus areolatus*	
Arthropoda	Malacostraca	Decapoda	Cambaridae	*Procambarus paradoxus*	
Arthropoda	Malacostraca	Decapoda	Palaemonidae	*Cryphiops luscus*	X
Arthropoda	Malacostraca	Decapoda	Pseudothelphusidae	*Tehuana veracruzana*	
Chordata	Amphibia	Anura	Craugastoridae	*Craugastor polymniae**	X
Chordata	Amphibia	Anura	Hylidae	*Bromeliohyla dendroscarta**	X
Chordata	Amphibia	Anura	Hylidae	*Charadrahyla altipotens*	X
Chordata	Amphibia	Anura	Hylidae	*Charadrahyla trux*	
Chordata	Amphibia	Anura	Hylidae	*Ecnomiohyla echinata*	X
Chordata	Amphibia	Anura	Hylidae	*Plectrohyla calvicollina*	X
Chordata	Amphibia	Anura	Hylidae	*Plectrohyla celata*	X
Chordata	Amphibia	Anura	Hylidae	*Plectrohyla cembra*	X
Chordata	Amphibia	Anura	Hylidae	*Plectrohyla cyanomma*	X
Chordata	Amphibia	Anura	Hylidae	*Plectrohyla ephemera**	X
Chordata	Amphibia	Anura	Hylidae	*Plectrohyla hazelae**	X
Chordata	Amphibia	Anura	Hylidae	*Plectrohyla siopela*	
Chordata	Amphibia	Anura	Hylidae	*Plectrohyla thorectes**	X
Chordata	Amphibia	Anura	Ranidae	*Lithobates omiltemanus*	
Chordata	Amphibia	Anura	Ranidae	*Lithobates pueblae*	
Chordata	Amphibia	Anura	Ranidae	*Lithobates tlaloci*	
Chordata	Amphibia	Caudata	Plethodontidae	*Chiropterotriton magnipes**	
Chordata	Amphibia	Caudata	Plethodontidae	*Pseudoeurycea ahuitzotl**	
Chordata	Amphibia	Caudata	Plethodontidae	*Pseudoeurycea anitae*	X
Chordata	Amphibia	Caudata	Plethodontidae	*Pseudoeurycea aquatica*	X
Chordata	Amphibia	Caudata	Plethodontidae	*Pseudoeurycea naucampatepetl*	
Chordata	Amphibia	Caudata	Plethodontidae	*Pseudoeurycea praecellens*	
Chordata	Amphibia	Caudata	Plethodontidae	*Pseudoeurycea tlahcuiloh**	
Chordata	Amphibia	Caudata	Plethodontidae	*Pseudoeurycea unguidentis*	X
Chordata	Amphibia	Caudata	Plethodontidae	*Thorius infernalis*	
Chordata	Amphibia	Caudata	Plethodontidae	*Thorius minydemus*	
Chordata	Amphibia	Caudata	Plethodontidae	*Thorius munificus*	
Chordata	Amphibia	Caudata	Plethodontidae	*Thorius narismagnus*	
Chordata	Aves	Charadriiformes	Scolopacidae	*Numenius borealis*	
Chordata	Aves	Piciformes	Picidae	*Campephilus imperialis*	
Chordata	Aves	Procellariiformes	Hydrobatidae	*Hydrobates macrodactylus*	
Chordata	Aves	Procellariiformes	Procellariidae	*Pterodroma caribbaea*	
Chordata	Mammalia	Rodentia	Cricetidae	*Peromyscus guardia*	
Chordata	Mammalia	Rodentia	Cricetidae	*Peromyscus mekisturus*	
Chordata	Mammalia	Rodentia	Heteromyidae	*Dipodomys gravipes*	

Notes to Appendix 2

Craugastor polymniae – This species probably should not be flagged as Possibly Extinct. Sean Rovito found this species in 2009 (see page 118 for more information). We say "probably" here (and in some others below) because we do not know enough about the continued existence of the species to make a firm determination.

Bromeliohyla dendroscarta – This species might have been refound. See footnote 19, page 121 for more information.

Plectrohyla ephemera – This species should not be flagged as Possibly Extinct. See our section on Cerro de las Flores for more information (page 213).

Plectrohyla hazelae – This species should not be flagged as Possibly Extinct. It was refound at two localities (Heimes & Aguilar 2011). For more information see page 107.

Plectrohyla thorectes – This species should not be flagged as Possibly Extinct. It was refound in 2007 and again in 2009 in several streams (see Delia *et al.* 2013).

Chiropterotriton magnipes – This species probably should not be flagged as Possibly Extinct. Sean Rovito found this species in 2010 in Hidalgo, at the type locality of *Chiropterotriton mosaueri*, which he also found (Rovito 2010).

Pseudoeurycea ahuitzotl – This species probably should not be flagged as Possibly Extinct. Sean Rovito and colleagues found this species near its type locality in 2010 (S. Rovito, pers. comm.).

Pseudoeurycea tlahcuiloh – This species probably should not be flagged as Possibly Extinct. Sean Rovito and colleagues found this species near its type locality in 2010 (S. Rovito, pers. comm.).

Two Issues

The Appendix 2 table raises a couple of issues that might interest the reader. First, the version of the Red List here is more current than the rest of the document (2014.3 vs. 2013.2). We have looked at the complete lists of the two and few changes to Red List occurred for the species in our region. *Pseudoeurycea anitae*, which had been CR, is now CR (PE). This designation makes sense, and it only makes our argument for *Plectrohyla labedactyla* to be CR stronger (page 238). *Pseudoeurycea unguidentis* has been added to the list of CR (PE) species, which again makes perfect sense.

Second, we have a small editorial comment to make relevant to *Charadrahyla altipotens*. The species is known from two localities in Oaxaca, but it is now listed as CR (PE). We did not discuss this species anywhere in the book. Being in two locations far apart from each other disqualifies the species from being an AZE trigger (which would require a single known site). A similar situation occurs with *Plectrohyla cembra* and *Bromeliohyla dendroscarta*, which we have discussed a bit. To us, any such species, if found should automatically trigger an AZE site wherever someone re-discovers it. The question then becomes, why not list all CR (PE) species as AZE trigger species with unknown locality data as a way to encourage people to look for them? Or at least, why not place these species on a companion list to the AZE list as priority species to seek? If our notes to Appendix 2 are indicative of anything, it is that some of these species might be found, but time is limited so we should do all we can to get folks in the field trying to track them down.

Appendix 3. Summary of the Five Criteria (A-E) Used to Evaluate if a Taxon Belongs in a Threatened Category (CR, EN or VU). Reproduction of table 2.1 from IUCN-SPSC (2014).

A. Population size reduction. Population reduction (measured over the longer of 10 years or 3 generations) based on any of A1 to A4

	Critically Endangered	Endangered	Vulnerable
A1	≥ 90%	≥ 70%	≥ 50%
A2, A3 & A4	≥ 80%	≥ 50%	≥ 30%

A1 Population reduction observed, estimated, inferred, or suspected in the past where the causes of the reduction are clearly reversible AND understood AND have ceased.

A2 Population reduction observed, estimated, inferred, or suspected in the past where the causes of reduction may not have ceased OR may not be understood OR may not be reversible.

A3 Population reduction projected, inferred or suspected to be met in the future (up to a maximum of 100 years) *[(a) cannot be used for A3]*.

A4 An observed, estimated, inferred, projected or suspected population reduction where the time period must include both the past and the future (up to a max. of 100 years in future), and where the causes of reduction may not have ceased OR may not be understood OR may not be reversible.

based on any of the following:

- **(a)** direct observation *[except A3]*
- **(b)** an index of abundance appropriate to the taxon
- **(c)** a decline in area of occupancy (AOO), extent of occurrence (EOO) and/or habitat quality
- **(d)** actual or potential levels of exploitation
- **(e)** effects of introduced taxa, hybridization, pathogens, pollutants, competitors or parasites.

B. Geographic range in the form of either B1 (extent of occurrence) AND/OR B2 (area of occupancy)

	Critically Endangered	Endangered	Vulnerable
B1. Extent of occurrence (EOO)	< 100 km²	< 5,000 km²	< 20,000 km²
B2. Area of occupancy (AOO)	< 10 km²	< 500 km²	< 2,000 km²
AND at least 2 of the following 3 conditions:			
(a) Severely fragmented **OR** Number of locations	= 1	≤ 5	≤ 10
(b) Continuing decline observed, estimated, inferred or projected in any of: **(i)** extent of occurrence; **(ii)** area of occupancy; **(iii)** area, extent and/or quality of habitat; **(iv)** number of locations or subpopulations; **(v)** number of mature individuals			
(c) Extreme fluctuations in any of: **(i)** extent of occurrence; **(ii)** area of occupancy; **(iii)** number of locations or subpopulations; **(iv)** number of mature individuals			

C. Small population size and decline

	Critically Endangered	Endangered	Vulnerable
Number of mature individuals	< 250	< 2,500	< 10,000
AND at least one of C1 or C2			
C1. An observed, estimated or projected continuing decline of at least (up to a max. of 100 years in future):	25% in 3 years or 1 generation (whichever is longer)	20% in 5 years or 2 generations (whichever is longer)	10% in 10 years or 3 generations (whichever is longer)
C2. An observed, estimated, projected or inferred continuing decline AND at least 1 of the following 3 conditions:			
(a) **(i)** Number of mature individuals in each subpopulation	≤ 50	≤ 250	≤ 1,000
(a) **(ii)** % of mature individuals in one subpopulation =	90–100%	95–100%	100%
(b) Extreme fluctuations in the number of mature individuals			

D. Very small or restricted population

	Critically Endangered	Endangered	Vulnerable
D. Number of mature individuals	< 50	< 250	**D1.** < 1,000
D2. *Only applies to the VU category* Restricted area of occupancy or number of locations with a plausible future threat that could drive the taxon to CR or EX in a very short time.	-	-	**D2.** typically: AOO < 20 km² or number of locations ≤ 5

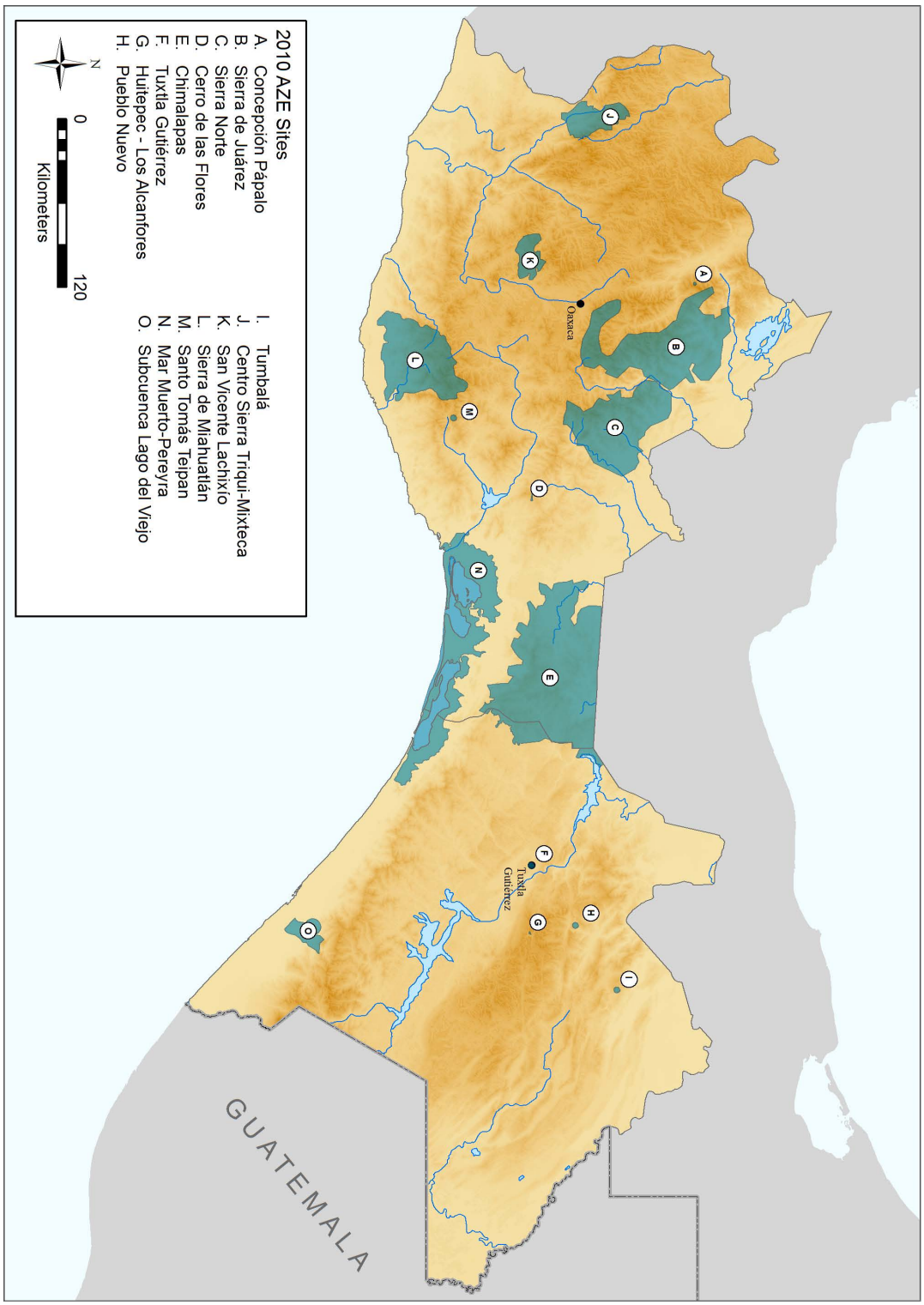
E. Quantitative Analysis

	Critically Endangered	Endangered	Vulnerable
Indicating the probability of extinction in the wild to be:	≥ 50% in 10 years or 3 generations, whichever is longer (100 years max.)	≥ 20% in 20 years or 5 generations, whichever is longer (100 years max.)	≥ 10% in 100 years

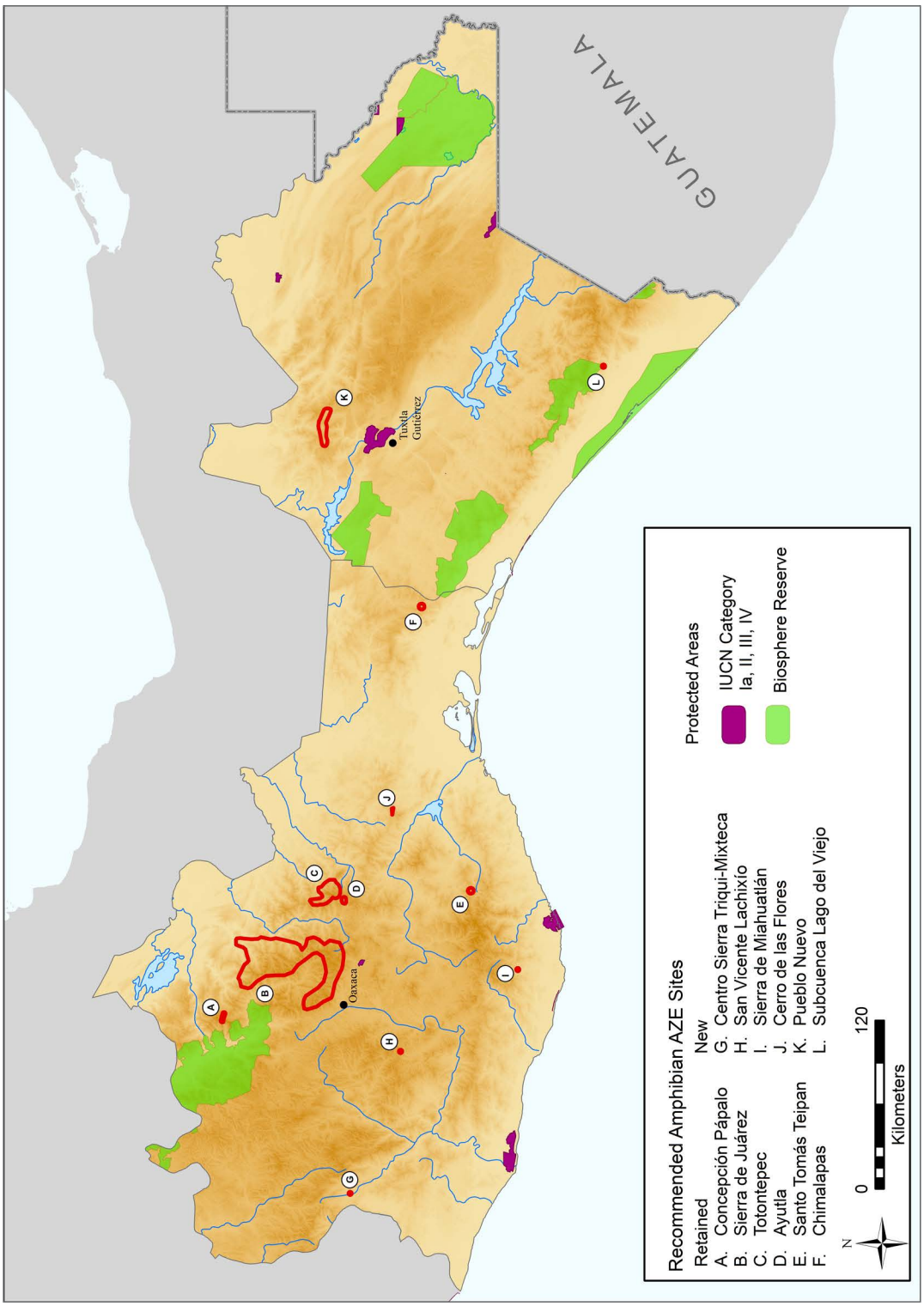
1 Use of this summary sheet requires full understanding of the *IUCN Red List Categories and Criteria* and *Guidelines for Using the IUCN Red List Categories and Criteria*. Please refer to both documents for explanations of terms and concepts used here.

Reference

IUCN-SPSC (IUCN Standards and Petitions Subcommittee). 2014. *Guidelines for Using the IUCN Red List Categories and Criteria. Version 11.* Available at: <http://www.iucnredlist.org/documents/RedListGuidelines.pdf>. Downloaded 31 May 2014.



Appendix 4. Official 2010 AZE sites for Chiapas and Oaxaca. From: AZE (Alliance for Zero Extinction). 2010. 2010 AZE Update. Available at: <www.zeroextinction.org>. Downloaded 20 May 2014.



Appendix 5. Protected Areas (IUCN Categories I-IV and UNESCO MAB Biosphere Reserves) in Oaxaca and Chiapas. Our recommended AZE sites are overlaid in red.

Acronyms and Abbreviations

AArk – Amphibian Ark

ACAP – Amphibian Conservation Action Plan

ASG – Amphibian Specialist Group

AZE – Alliance for Zero Extinction

Bd – Batrachochytrium dendrobatidis

CDI – Comisión Nacional para el Desarrollo de los Pueblos Indígenas

CEPF – Critical Ecosystem Partnership Fund

CFE – Community Forest Enterprise

COINBIO – Conservación Comunitaria de la Biodiversidad

CONAFOR – Comisión Nacional Forestal

CONAGUA – Comisión Nacional del Agua

CONANP – Comisión Nacional de Áreas Naturales Protegidas

CI – Conservation International

ECOSUR – El Colegio de la Frontera Sur

ENSO – El Niño–Southern Oscillation

EOO – extent of occurrence

ERA – Estudios Rurales y Asesoría

FSC – Forest Stewardship Council

GBIF – Global Biodiversity Information Facility

INEGI – Instituto Nacional de Estadística y Geografía

IPCC – Intergovernmental Panel on Climate Change

IUCN – International Union for Conservation of Nature

LYO – last year observed

NGO – non-governmental organization

NGS – National Geographic Society

OIE – World Organization for Animal Health

PCR – polymerase chain reaction

PROFEPA – Procuraduría Federal de Protección al Ambiente

Red List – *IUCN Red List of Threatened Species*™

SEMARNAT – Secretaría de Medio Ambiente y Recursos Naturales

UNAM – Universidad Nacional Autónoma de México

UNEP – United Nations Environment Programme

WDPA – World Database on Protected Areas

WWF – the abbreviation, WWF, originally stood for "World Wildlife Fund," but now the initials are the official name of the organization

ZOOMAT – Zoológico Regional Miguel Álvarez del Toro

IUCN Red List Categories (for more on these see page xix and Appendix 1, page 304)

EX – Extinct

EW – Extinct in the Wild

CR – Critically Endangered

EN – Endangered

VU – Vulnerable

NT – Near Threatened

LC – Least Concern

DD – Data Deficient

PE – Possibly Extinct is not an IUCN category, but applies to a subset of CR species

Museums

AMNH – American Museum of Natural History

ANSP – The Academy of Natural Sciences (Philadelphia, Pennsylvania)

CAS – California Academy of Sciences

EBUAP – Laboratorio de Herpetologia, Escuela de Biologia, BUAP

ECOSUR-SC – El Colegio de la Frontera Sur, Unidad San Cristóbal

IBUNAM – Instituto de Biología, Universidad Nacional Autónoma de México

IBUNAM-CNMA – Instituto de Biología, Universidad Nacional Autónoma de México - Colección Nacional de mamíferos

INHE – Instituto de Historia Natural y Ecología

KUH – University of Kansas Natural History Museum & Biodiversity Institute - Herpetology (in other works this has been abbreviated as KU or KUNHM; the latter for "University of Kansas Natural History Museum and Biodiversity Research Center")

LSU – Louisiana State University Museum of Natural Science

MCZ – Museum of Comparative Zoology at Harvard University

MSB – Museum of Southwestern Biology – Division of Amphibians & Reptiles (University of New Mexico)

MSUM – Michigan State University Museum (vertebrate specimens)

MVZ – Museum of Vertebrate Zoology at the University of California, Berkeley

MZFC – El Museo de Zoología de la Facultad de Ciencias de la Universidad Nacional Autónoma de México

MZFC-Herp – Collection of Herpetology of the Museum of Zoology "Alfonso L. Herrera", UNAM

TCWC – Texas Cooperative Wildlife Collection (The Natural History Collection at Texas A&M University)

UCM – University of Colorado Museum

UIMNH – University of Illinois Museum of Natural History

UMMZ – University of Michigan Museum of Zoology

UNAM – Universidad Nacional Autónoma de México

USNM – Smithsonian Institution National Museum of Natural History

UTA – University of Texas Arlington Amphibian and Reptile Diversity Research Center

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