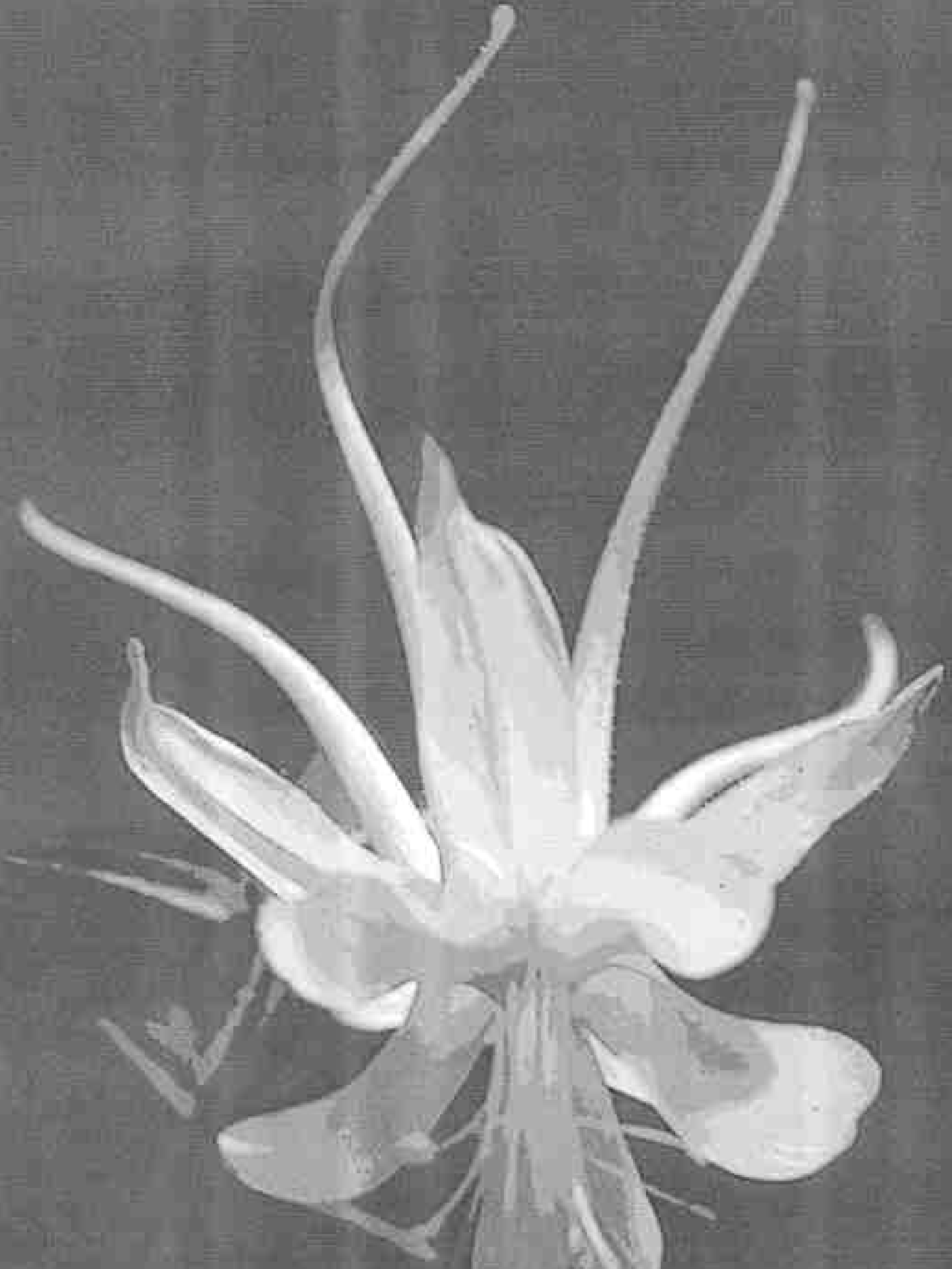
Biology



Chapter 6

Archiving the Future (Keynote Address)

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I think the whole concept of a keynote speech is a fairly interesting idea. Certainly at this late hour in this whole array of listening to papers and everything, I know you're tired. They've given me this little thing that says, "keynote speaker," and every one of you, I know, have looked at me several times and thought, "Keep it short, Bucko." And then I chose a title that says, "Archiving the future." Well, if you're into words you know that "archive" is a noun and not a verb. But when we finish, it will be a verb, because it is an active process. And I don't know if you noticed or not, but there were at least two times in these meetings when it was used as a verb.

I should start off by saying that a keynote talk should be several things. It should set the tone; it should be entertaining, certainly if people have had alcohol it certainly should be entertaining; and it certainly should be short. I hope that I will be able to do that. This is a really tough talk to give; it's from my former life. I need to bring some ideas together for you and I hope that you will work with me in developing these ideas because I want to talk about where science has gone. I want to talk about some of the good and some of the bad. I hope I don't burden you too much. I'll try to make it all very simplistic and not in any real details, but if you'll work with me on that, then we'll get to the crown jewel and talk about the Guadalupe Mountains, and we will try to keep it short.

I should tell you that all the things we do at Texas Tech we do as a team. There is very little honor and award for individuals. We work together, and there are a lot of people that have done lots of things. Some of the names that I should mention are Clyde Jones, Kelly Allen, Richard Monk, Anton Nekrutenko, and a whole bunch of other people. I'll be showing some slides of individuals and bring them up as we go along. I love working with other people. I got to thinking about this one day. There are only about 10 papers in my life that I've published by myself. I've only done one thing in my life by myself, and I was wishing somebody else was there, so I know I'm a people person.

I first visited the Guadalupe Mountains in 1968. I cannot find my field notes; we're actually in the process of redoing the building and moving things, so I couldn't find my field notes. But, the first time I climbed up to the Bowl I struggled through the whole idea of finding who could give me permission to go up there. We went up to the Bowl and we stretched the net over this [place], and there were a lot of things that happened that day. I was the same age at that time as the Guadalupe Mountains are today; I was 25 years old. At that time, most of you people, a lot of you people are much younger, and you don't understand how that everything hadn't been on TV at that time. Now when you try to be an educator, everything has already been on TV. They've seen desert-mountain bighorns fight; they've seen lions kill; they've seen everything. There is nothing that hasn't been portrayed on TV. We climbed up there, and we got there late in the afternoon, and two bull elk started bugling at each other. They came down out of the hills breaking trees; this was serious fighting. They came down and they locked horns and they put on one of the most magnificent fights I've ever seen. We were probably about 50 or 60 meters away, and Jim Bull, who is now a professor at the University of Texas at Austin, and I sat there with our mouths open. And there was another little interesting thing about this. There was a little fork-horn that was there with them, and these two big bulls were just knocking the daylights out of each other. This little fork-horn was running around and then it'd leap, then it would run around one side and it'd leap, then it would run around…, and you could just see it saying, "Some day, someday, I'm going to be there and I'm going to be doing this." Of course, they didn't pay any attention to that so they went on about their business. But that was my first. Jan, you asked us to talk about—and that won't be the last time she asks us to talk about—our first experiences or our best experiences in the park.

"Archiving the future"—archive is a noun and it means to hold in trust, so I want to talk about the concept of holding things in trust and where the scientific and the conservation communities associated with this are going. When we published the first *Biological Investigations of the Guadalupe Mountians*, Hugh Genoways and I were very young and we struggled to get this done. I read through it the other day when we reprinted it, or read most of it, and I was pleasantly surprised that there was an awful lot of good work done there. We did the mammal survey, and I want to impress you with where all there are collecting sites. I didn't go to all the collecting sites but I do think we actually earned our spurs for visiting the Guadalupe Mountains. There are a lot of voucher specimens that are in the archives at Texas Tech.

Figures 1-3 are diagrams out of David Schmidly's book, *The Mammals of Texas*, and I want you to look at what this really means about the critical aspect here of this fauna. If you look at the total volume of land that is in these various regions, the post oak savannah, the pineywoods, and then you look over at the extreme right up at the top, the Trans-Pecos of Texas, there are almost 90 species of the mammals that are

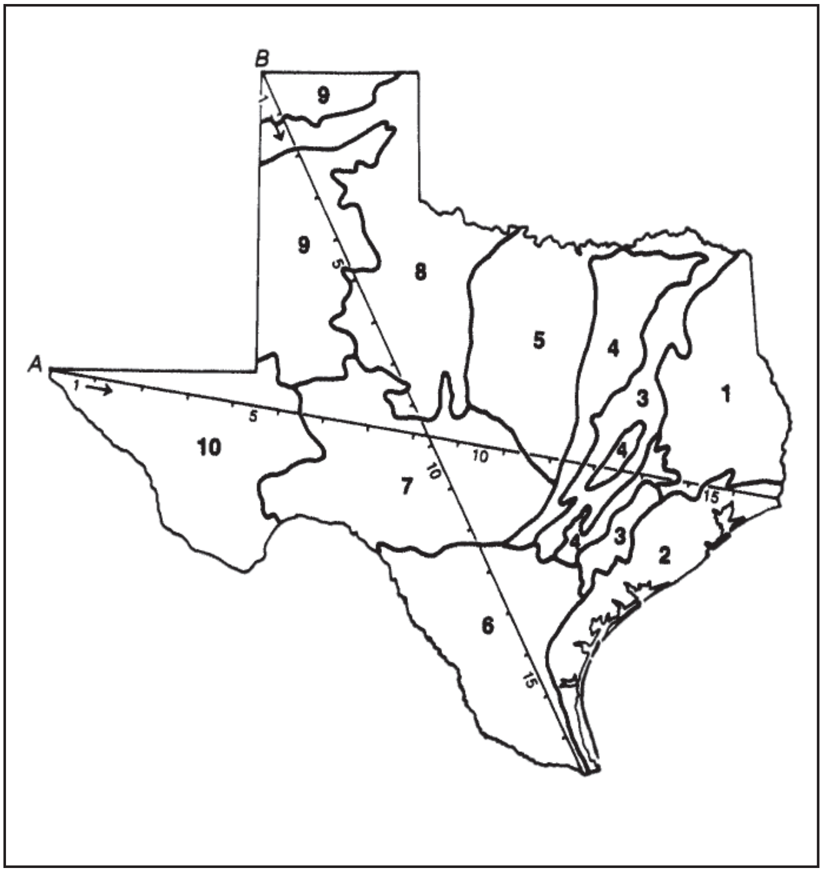

Figure 1. Map of Texas shows major vegetative regions and the location of two transects along which species diversity was analyzed. Transect A stretches from El Paso to Beaumont; Transect B stretches from Dalhart to Brownsville. 1=Pineywoods, 2=Gulf Prairies and Marshes, 3=Post Oak Savannah, 4=Blackland Prairies, 5=Cross Timbers and Prairies, 6=South Texas Plains, 7=Edwards Plateau, 8=Rolling Plains, 9=High Plains, 10=Trans-Pecos, Mountains and Basins. (From *Mammals of Texas* by David J. Schmidly, 1962. Map according to Gould, "Texas Plants: A Checklist and Ecological Summary." Texas Agricultural Experiment Station, MP-585. Used by permission of Texas Parks and Wildlife Press.)

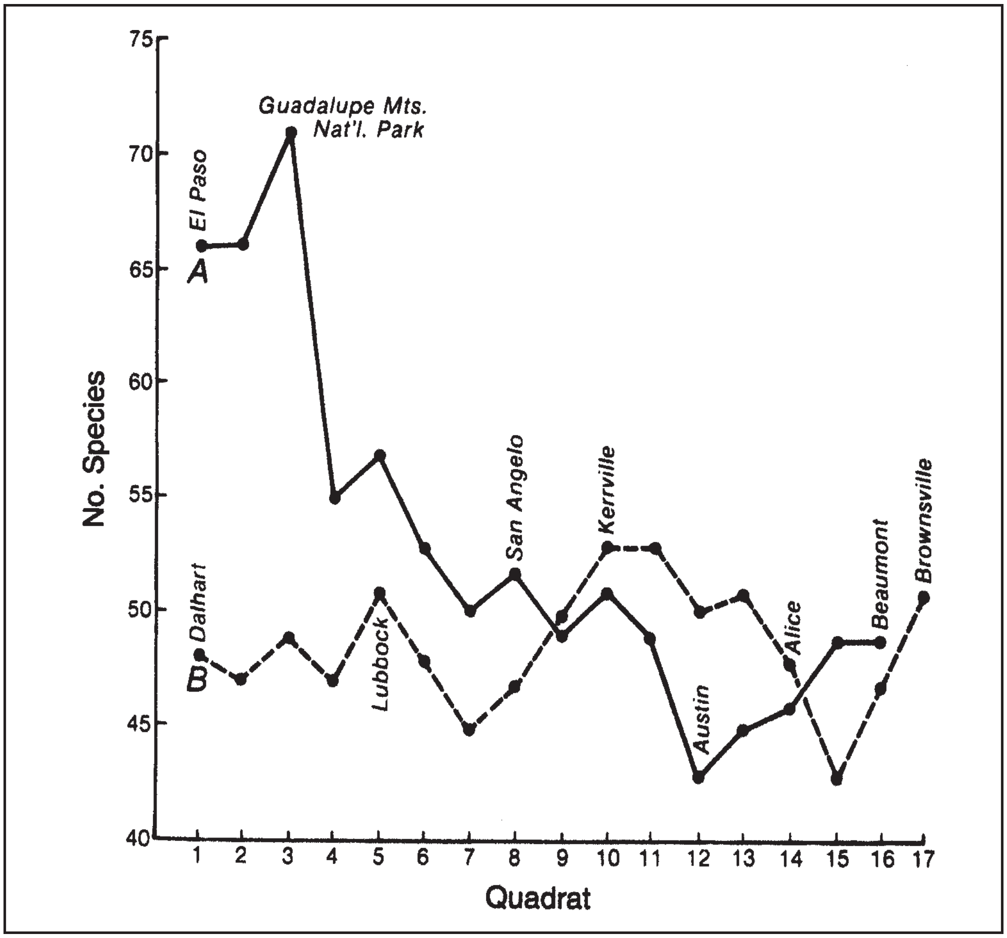

Figure 2. Species diversity plots for the quadrants along the two transects (A and B) shown in Figure 1. (From *Mammals of Texas* by David J. Schmidly. Used by permission of Texas Parks and Wildlife Press.)

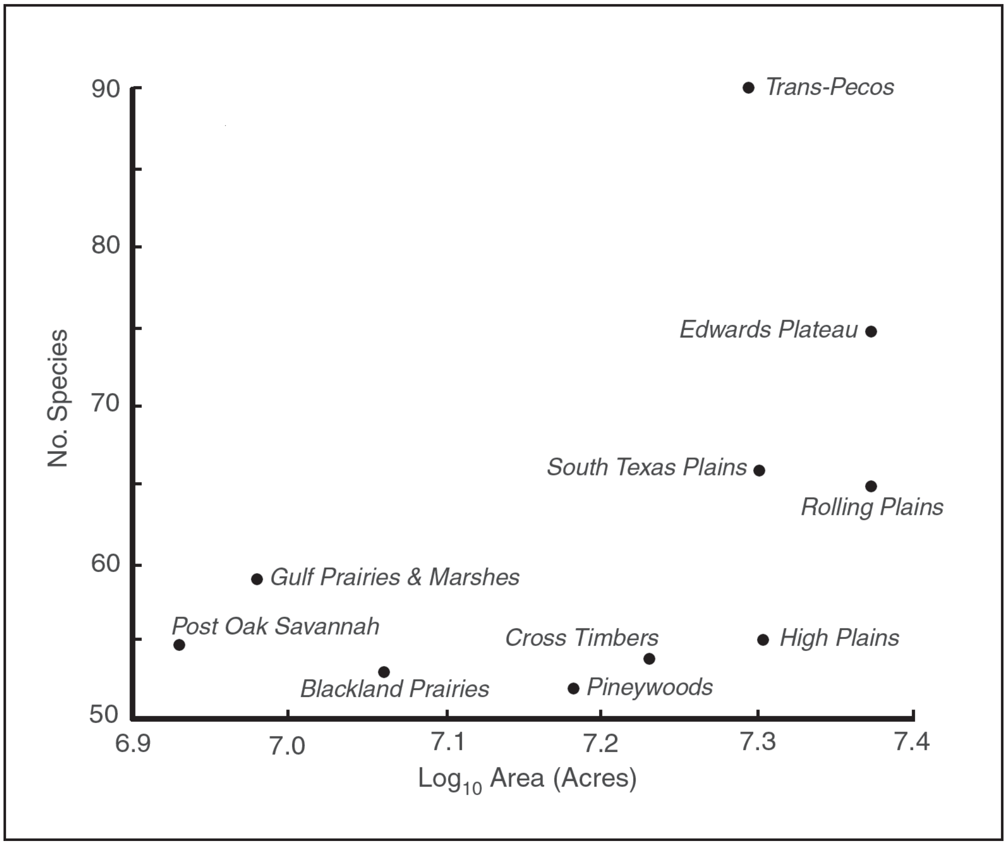

Figure 3. Plot shows the number of species versus the area for each of the vegetative regions of Texas shown in Figure 1. (From *Mammals of Texas* by David J. Schmidly. Used by permission of Texas Parks and Wildlife Press.)

known from Texas, more than half are known from the Trans-Pecos of Texas. The Guadalupe Mountains mammal survey that we did revealed that there are 65 species recorded from the Guadalupe Mountains in the last 150 years, and nine of those have been extirpated. They did not exist at the park at the time that Hugh and I finished our work. I do think prairie dogs should be introduced into Dog Canyon. *Chaetodipus*, a pocket mouse, is a small thing, but it was probably overgrazing that caused this animal to become extinct and we do believe that it doesn't exist here anymore. The wolf has gone, but there is some effort to reintroduce it. The grizzly bear is not going to be back. I doubt we're going to get it back anytime soon. Merriam's elk is an awesome animal. We need to know, "How different was Merriam's elk?" We have elk back here, but they aren't Merriam's elk—that's a biological entity and we really need to know how different that is, and I would certainly like to try to do some of that work sometime. White-tailed deer—I talked to Fred the other day and he does not think it's moved back in. *Antilocapra* was devastated across the whole United States and there are very, very small groups left. Bison—what can I say, bison is making a comeback but the [natural activity of] bison is gone, and *Ovis canadensis*, the desert bighorn. I want you to look at that and think about with me for just a moment what that means for the ecosystem. You're taking nine major [animals out of the ecosystem] with a couple of exceptions. The only animal that doesn't impact the ecosystem in a great fashion is *Chaetodipus*, and it may be really important, too. It has little pouches in its cheeks and carries things around and buries them, and it may really be critical to the survival of certain kinds of ecosystems. So this is a very significant loss, and it's not likely to be fixed anytime soon.

I want to talk for a minute about some of the changes that have taken place. We archived a lot of voucher specimens from here, and those are available to the scientific community. It's really important that we document what was there. Robert Baker may not be able to correctly identify specimens, and whether or not I did, if we leave a specimen there for these people to look at [we have an invaluable record]. We've looked at some of the other Bailey stuff, and so forth. But it really is important and it's going to become [more so in the future]. I'm going to build a case, but it's only [a] beginning. Our mammal collection at Tech, when I got there had about 5,000 specimens, now it has somewhere around 76,000, representing 20 orders of mammals, 94 families, 478 genera, and almost 1,100 species, and they come from all over the world. But certainly, one of our best representations is from the Guadalupe Mountains. Most of them are in [museum storage] cases, and Tech does have a very real commitment to the museum concept. They have a very real commitment to saving the museum stuff. In fact, there are a lot of collections that are being abandoned, and we're working toward being able to take those abandoned collections and to protect and save them for future scientists because we shouldn't lose sight of the fact that this is our record. These are our baseline data.

Another thing we've done is go to the concept of bar codes. When we go to the field now, we do one of two things. We either punch data into a computer—we don't write on any tags, we simply take a computer or we take one hard copy when it's back and we type from that one hard copy—or we simply download global positioning coordinates, and we take photographs. There's a higher standard now. When we get back, we catalog. We simply push a button and it catalogs all those specimens, and we can catalog a thousand specimens with the push of a button. It prints out all the information that goes on the tag. No longer do you have guys writing in there in ways you can't read. All of that is printed out and goes on the tag in a [legible] fashion. We can print out a field catalog; we can print out a catalog for the museum; we can print out a catalog of all frozen tissues. All of that now is pulled together, and we think it has reduced our error rate tremendously. The young man who did this is on our staff, his name is Richard Monk, and he has done an outstanding job. We were trying to do bar codes about 10 years ago, but it was just not the right time. All of these things have a time and place. Right now we're just about where Albertson's and United Supermarket are. I don't know whether I ought to feel secure or whether I ought to be asking why we are so far behind. But, basically what we do is, when we make a loan, we now go out and read the bar code and it prints out what goes on the loan sheet. So no longer is there all this tedium and so forth that goes along with it.

We also save frozen tissues. I want to tell you how important all these things are. We've talked tonight already about libraries, and these are absolute libraries. When we collect a mouse or a bat or a grizzly bear, or whatever you can get your hands on, we save those tissues. We literally save liver and heart and kidney and lung and blood and muscle and everything else that we can save. The reason you do that is every one of those is an absolute wealth of information. Every one of those is a library. Every one of those has all the information about the history of life and the DNA code. There are pieces of DNA in there that unite all of life together, us with arche-bacteria. There are pieces of stuff in there that identify every individual as being totally unique, and we can pull that out and read it now; the book is readable. You also can do systematics; you can do toxicology—how much genetic change has been induced by whatever that mouse had in the way of exposure to toxins. You can do forensics. You can tell something about the animal, where it was from. You can tell multiple paternity, whether or not this pregnant female animal had multiple males inseminating the litter. Medicine—There are genes in there that can be pulled out that are going to be used in making trans-genics. There's disease—hantavirus and all the other diseases that we can look at and see whatever. Right now, the problem is that we just don't have the imagination. The technology has gone far enough and soon it's going to go a lot further and those things are going to be absolutely powerful in helping us make management decisions. Agriculture—Genes are going to be brought out for trans-genic things. Recreating history—There are a lot of things from these animals you're going to be able to do, to recreate a lot of events in history. And then all the other things that I haven't managed to think of yet. Maybe somebody will. We keep all these things in liquid nitrogen. We have a facility where we have 10 ultracolds [refrigerators], and there are back-up ultracolds that aren't plugged in [so] if an ultracold goes down [it can be replaced]. Somebody walks through the building every day; somebody deals with it.

The program is a very international program. We work with Ukrainian, Canadian, and Mexican scientists, and most of our work today deals with international issues, not just simple things. Our frozen tissue collection holds tissue from about 26,000 specimens from 16 orders and 61 families. That's a lot of collecting and saving and a lot of people have spent a lot of time doing it. We have things like wooly mammoth. We were able to get something out of an American wooly mammoth up in the Arctic. We've got gorillas and whooping cranes and all other kinds of endangered species and animals from Chernobyl, Texas resources, and all kinds of baseline data.

We've done a lot of work at Chernobyl. Chernobyl is a very fascinating place. There is a lot of biology to be learned at Chernobyl, and our question, our research effort there is, "what are the biological consequences of this?" The truth is that [the] Chernobyl [nuclear accident] is not as detrimental to life as is normal human activity where there is no contamination. In other words, we went in, we set up grids, and we found the most radioactive spot. This was the ultimate search. Where is there more radioactivity than anywhere else on the face of the earth? It's actually not at Chernobyl; it's at a place called Chelyabinsk in Russia, Siberia. So we went to this place, and we set out the grids, and there's more life because there is no over-grazing or over-farming, and the habitat is deep and good. There are more mice per trap-night there and there is no species of mammal missing. If you were to drive through there, you would see more moose and more roe deer and more Russian wild boar and more foxes and rabbits and everything than you would ever see out where normal people live and they farm and they take care of things. We've written a paper, although no one is really happy about publishing it. It's called, "How to create a wildlife preserve: the world's worst nuclear power plant disaster." In reality, we found a hawk's nest on the ground where the Geiger counter was essentially pegged, and they were hatching on the ground, and we cannot find any evidence of radiation that is doing anything that we can detect and show as effect. There are no monsters. The whole ordeal is blown out of proportion. I'm not telling you that it's not bad. I wouldn't want my kid sleeping on the ground over there. I'm just telling you that it's not as bad. If my kid had to sleep on the ground or smoke, I'd probably let him go there before I'd let him smoke cigarettes.

Here is how we use this. Terry Yates is at the University of New Mexico. He's one of my Ph.D. students. When the Four Corners disease came out, there was a big newspaper release of stories saying that this is probably just a military biological warfare agent that's available and has been turned loose and escaped. What we did is, we took all the *Peromyscus maniculatus* we had in his collection and in our collection—his collection is New Mexico—and we sent them off to CDC, and this was all the stuff that was collected long before the Four Corners disease was described. We could show that this was not something from the military. It was a disease that had killed people in the past, but we just didn't have the medical skills to recognize it. It wasn't in the multiple choice answers that physicians have for, "this is what you died with." So they [said the patient] died with a respiratory ailment.

I have this obsession with collecting. I love animals, but people often ask me, "Do you ever feel guilty?" Let me tell you a story about the time I got talked into not keeping something, and I really regretted it. We took a mammalogy field trip to a place that I owned and there were about 1,000 thousand-pound bales of hay, and it had been there for a couple of years. We were taking a tractor and driving up and picking up those bales and shaking those bales and the mice would just rain out! There was *Peromyscus* and all kind of things. This was mammalogy! We were talking today about how these people love their work, and I'm telling you, this was a party! So, everybody is diving under these bales and catching all these mice, and we took several hundred, maybe thousands, and we brought enough back that each mammalogy student could prepare two specimens. I took them over to the collection and the curator, the assistant that I had then, said, "Robert, we've got"—obviously we've got a lot of *P. maniculatus*—"too many *P. maniculatus* already. Why don't you just not save those things?" I struggled with that, and we saved 10. That was before hantavirus showed up. Once when hantavirus showed up, then the question was—nobody [from that collecting trip] got sick—"In breathing all that mouse excrement and hay and everything else, did these people not catch hantavirus because the mice were not carrying the disease or did they not catch it because it is hard to transmit to people?" The answer was very simple. Six of the 10 mice we saved had hantavirus, had active infections. Today, if we took a class out and did that, and somebody got sick, we'd be sued for a billion dollars; and probably appropriately so. But at that time, we didn't know that and mammalogy was an art form. That was meaningful information. I only wish I'd have saved 20, or 30, or 40, or all the ones that were prepared by those students.

We have a contract with Texas Parks and Wildlife that is funded by the state legislature. What we are supposed to do between now and the year 2000, is to visit all the land that is controlled by Texas Parks and Wildlife. We are to collect and present them with a record of what's there—UTM coordinates and photographs of all the taxa—and we're supposed to save these livers, kidneys, hearts, lungs, and everything else and archive them. The person that's actually doing most of the work is Robert Bradley and he's doing a great job. The other person who is playing a role in all this is Nick Parker. He's always up in the air about something, so I'll have to give him some credit. And, of course, David Schmidly, who we're recycling from Texas A&M. We're certainly glad he's a vice-president at Tech now.

The kind of data we're pulling together gives you a new view. This is something that Kelly Allen did. Today, Nick Parker was pointing out how the habitat is very restricted for *Peromyscus truei* in the Panhandle, and they live on the very steep sides of the canyons there. But more importantly, the Guadalupe Mountains animals, habitat-wise, are absolutely different than the animals up there. Now what that usually means is that you don't have the same species. So what we need to do, we need to pick up on these kinds of things, and probably when it's all said and done, *Peromyscus truei* in the Texas Panhandle will not be recognized as the same species. This is the kind of thing you get from Texas GAP and from doing those kind of animal associations with habitat, but we can test it; we can work on that.

We are committed to putting all the material that we can on the World Wide Web to deal with students. I have an 11-year- old son, and he's a computer nerd. I try to break his arms and everything whenever he goes in there, but so far I haven't been able to keep him away from it. When he was eight-years old, I picked him up from school one day and I asked, "Bobby, do you have any homework?" And he said, "Yes, sir, I do." And I asked him, "Well, what is it?" And he said, "I'm supposed to compare and contrast the public policy and positions of Bill Clinton and Newt Gingrich." And I said, "Just where are you going to find that?" And he said, "Oh, I'll just get it off the Web." So I thought, "I'll just go watch," and I did. My son went in there and he started clicking through this thing, and he started pulling all these things up that Newt Gingrich had said and that Bill Clinton had said. He started highlighting and pasting, and when he walked out of there he had a one-page statement on each of those and would be able to articulate it. I thought, "Holy cow!" We're missing something here. If that kid can go do that, we need to figure out, to get those children using, studying biology, and looking at all the agendas that we have.

The problem is that no longer are the students, the young people, involved outdoors. They're living in cities; there's more and more urbanization, and there's less and less opportunity to interact with nature. We need to fix it so they can interact with nature and they can see the Guadalupe Mountains and all of these things. So, we are about this [work]. We've set about to fix all this. We have *The Mammals of Texas* on the Web, on our home page, and so does Texas Parks and Wildlife. We work with them and when we get one of those things finished we put it on [the Web]. They actually own the copyright, so we have to play on their team, so I won't sound too magnanimous.

One of the things that's going to be exciting is that David Schmidly has looked at every [mammal] specimen that has been collected from the State of Texas, in any museum, anywhere. He said, "I didn't get them all right, I'm sure, but I got most of them right." I would bet money that, absolutely, he got most of them right. Some of the things that are at the Smithsonian, from that 1880 to 1905 (or 1903) biological survey of the State of Texas, are about 1,500 photographs that were made around 1900. Some of them were made by A. H. Howe, and you mammalogists know who that is. Unfortunately, we [at Tech] only have six that are from the Guadalupe Mountains, from Upper Dog Canyon, but there may be a substantial number more. Our plan is to have this so that everybody in the State of Texas can simply go on [the Web] and they can interface them by going to any county, or wherever they are, click on that, and have a list of all the photographs, then be able to pull them up. We hope to be able to go back and get as close as we can to UTM coordinates and other ways to let people be able to look at them. This is part of our history, and having that available, I think, will entertain a lot of people, a lot of ranchers, a lot of naturalists, and a lot of children as well.

One of the things that always worries me is I'm always saying, "Why are we doing this? Who called this meeting? What's the goal here? Where are we trying to get from this point?" I think one of the goals is to get scientists to communicate with each other to make information available. One of the goals is to communicate and have successful communication.

This is what Larry Henderson wrote in the introduction, "…preservation of outstanding ecological, scenic, cultural and other natural values in a place of untrammeled wilderness…." I've edited the beginning and the end of that [statement], but that's a very honorable goal and a very specific goal. That's out of the foreword to the second printing of *Biological Investigations in the Guadalupe Mountains National Park, Texas.* We need to conserve resources. We have just heard from the National Parks Conservation Association how that's really important. We need to avoid unnatural change. And am I uncovering a fight here, because there are people who say, "What is natural?" and the deconstructionists, humans, are just a part of it. I probably would like to take on that group a little bit, because I think that while it is true that the guys with spears and the guys with bows and arrows and perhaps even with rifles played a real role in selection and forcing ecosystems to go, I think the bottom line is that the problem that we are facing today is a different level and a different magnitude. It may still be natural, if you want to just call humans a part of the ecosystem, or whatever.

The other real big issue here is "What is change?" The human mind is an amazing thing. I can go to the women's basketball game playing UT-Austin, and I can thank the referees for the worst they ever were, and every call went against Tech. Everybody who's sitting over on that burnt orange side feels exactly the same way, except every call went against the UT ladies. We're both honest; we both saw the plays. I think it was E. O. Wilson who said that the human brain is made for survival; it's not made for accuracy in science and all that stuff. Here's the problem. What this means is that we have to back off. We have to learn how to work with ranchers. We've got to learn how to work with economic developers. We've got to learn how to work with all these people, and we've got to understand that how they see it is different than how we see it, and we've got to listen. We've got to build, and that's really critical, because we've got to understand that the human brain and the perception of change are different for everybody that sees it.

Here's the thing that really frightens me. There are 5.6 billion people on the face of the earth right now. There'll be 6.0 billion by the year 2000, and I don't know where this is going to end. But you know what? I have followed this for 25 years, and so far we have been very accurate in predicting how many people there are. We might be able to stop some of this. But the problem here is, go back to Chernobyl. At Chernobyl, we have a unique situation where those people are trying to survive, plowing the ground behind their house, growing their radishes and their cucumbers and their small wheat fields. In just the fact that they are trying to survive, they are destroying biodiversity at a level greater than what is the ultimate fear of all humans, and that's being exposed to radiation! We're doing that. We've got NAFTA [the North America Free Trade Agreement] down here. That's going to produce a lot of pollution in here. I think we need to archive—here we go with the verb again—we need to obtain samples from this mountain range to know how much pollution is in various birds and mammals and everything else that's out here so we have baseline data to know what's happening. What do we have to change, that kind of stuff.

This is a recent statement by E. O. Wilson, "To raise the rest of the world to the level of the United States in amount of food and amount of resources, using present-day technology, would require the natural resources of two more planets Earth." We are the very chosen people on Earth right now. This whole deal with Earth's population, I feel just like this. I was walking through a museum the other day, and I thought, "That guy must feel boxed in." I don't know what the solution to it is. I hope there are some people here smarter than I am or whatever.

Donald Dayton talked to us and he pointed out that a few years ago a major problem was, that getting the Guadalupes the magnitude of care that they needed required getting everybody together. I believe his words were, "We've got scientists crawling all over those mountains and they don't even know the other one is there." That's one of the reasons we held that symposium in 1975. I applaud this symposium, because this is doing the same thing. It's getting people to talk to each other; it's bringing new students in. We need that.

The magnitude of data that's out there is just overpowering. There's a whole new field developing. It's called bioinformatics. This is the definition that we dragged out of some home page: "systematic development and application of computing systems and computational solution techniques, analyzing data obtained by experienced modeling, database search and instrumentation regarding biological abstracts." Is that pedantic, or what? Basically, I think it says that we are using models to calculate values and to sort through the data. I decided with Nick Parker that we needed to redo this definition, so I think this is what we're talking about in bioinformatics: "the delivery of all these powerful data sets and its synthesis, and an understanding that they can interpret to decision makers and potential users, including the general public." That's our responsibility as scientists. Now, I agree that there are things that shouldn't be given out to the general public. There is sensitive data. But I think that this is where interpretation of research data needs to go. Bioinformatics is the hottest field in America, according to some of the magazines.

Here's a little breakdown on it. In 1995, the word first appears on the World Wide Web, and then in 1998 we are getting about 500 hits. There are symposia now on bioinformatics and all this kind of stuff, so it is a very rapidly developing field. Let me tell you where most of the application lies. Most of it lies in genomics. We now are sequencing; we are reading the DNA of everybody and his dog; yeast, bacteria, humans, cotton, everything you can think of. We're in there busily reading all of this stuff. An example is from a paper that we published, and it is a bat study. Bats have about 2.7 billion base pairs. That's a lot. What we wanted to know is, can we go in and find the piece of DNA that is unique to this bat that we took it from? Can we find a piece of DNA that identifies the species *Microtus waterhousii*? Can we find a piece of DNA that identifies the genus *Microtus*? Can we identify the family that it's in? Can we identify the suborder of bats? Can we identify the order? Can we go into these 2.7 billion base pairs and find them? So we made a library, which means what we did was we took this bat, isolated its DNA, cut its DNA up into 35,000 base pair pieces. That's still quite a bit of DNA. We put it in a vector, something that we could grow it in, *E. coli*. We grew it all up and then we did a bunch of scanning. This is the result of this thing. We actually were able to find 17 clones that identified *Microtus*, we identified 10 clones that identified Phyllostomidae and seven that identified the family, and 44 that identified Microchiroptera, and then we tested it to see if it would work. We took all the Noctillianoidea and put them all on there and saw that they all had that, and identified other things as well. So—we were trying to see—can we cheap and dirty pull out a piece of DNA that does that? The reason you want to do that is because you might want to identify a taxon, but you also might want to know, is this a mule deer? Is this a deer? Is it an elk? So if you pull out and go through this kind of method, you can have probes that tell you. If you've got a piece of meat or something, you can go through and see where these are. You can use it in forensics, you can use it in taxonomy, and you can use it in a whole bunch of things. We were very successful.

I think also one thing we need to do is to remember economics and the role that economics can play. Now economics can't solve everything, but we've got to remember that economics are really important. I will give you one real easy example. The two countries in Africa that have more elephants than they can stand are the two that prevent hunting. And I know that the people who want to save the elephants are also the people who don't want any hunting of elephants and don't want any sale of ivory and don't want this stuff. But in Zimbabwe, I believe the figures are something like this. They sell an elephant permit for $12,000 and they have sold something like 20,000 permits. The person who bought the permit has to get there and they've got to hire a guide and do whatever. As a result, the country has built schools, they've built hospitals and they've built everything else with this money, and you know what their problem is right now? At this moment, they have more elephants than the environment can handle. And in those countries that don't permit any hunting, people are poaching, trying to get a few pittances for whatever. The goal is to save the elephant, and this is the way that economically we can do that. Now I think they ought to just jack the price up higher to get more money for elephants and all that.

Another problem I think is pointed out by E. O. Wilson in his latest book called *Consilience*. You'll find he defined the word as, "the interlocking of causal explanation to cross disciplines." We do need to really back off and really look at the big picture. We need to not lose sight of the fact that—I know the most important thing to me is to protect my bats and my rats but in reality—the overall pattern is absolutely important. Natural science is moving away from the search for fundamental laws and elemental truths and reduction approaches toward highly organized systems.

This is the sixth of seven weekends in a row that I have been away from home going to meetings, and I went to the Texas genetics meetings not long ago, and I sat in on this meeting. So I'm sitting there listening to these people, and they are sequencing genes from the human genome. Now, there are 100,000 genes in the human genome, give or take 5,000 or something, and so they sequence these things and then they look at the promoter. You've got to have something to turn a gene on, and you've got to have something to turn it off. I'm sitting here and this guy's up there talking about the gene for cartilage. Well, you know, you've got cartilage here, and you've got cartilage in all the bones, and you've got to know when to turn it on and make cartilage. You don't want to make cartilage in your eyeballs, you want to make it where you need cartilage. You've got to know how to turn all that stuff on and everything. So this guy's going through it and he sequenced the whole gene, and he sequenced the promoter region, which tells it when to turn on. He has found four protein binding sites in this promoter region. He went over each one of them. He says, "Well this one's used when you develop cartilage; and the precursor for bone, this one binds here; and when you need to do this, this one binds in the ear and the nasal septum; and when you do this...." So he has gone through and he has worked all of this out. Wow! Right? I don't know whether I can stand listening to 100,000 genes or not, you know? I mean, what we have done is we have sequenced less than 7,000 genes. We have 93,000 more to go. I had attention span deficit syndrome long before it was a disorder, and I just wanted to scream and run out of the building. I'm sure it's absolutely important. I'm sure it's perfect, incredible, but you know, God help me, how many of those can I listen to and work with.

What I think I've tried to do is tell you, "Boy! There are a lot of powerful methods out there." There are computers and there are all kinds of things that we can use to address problems like biodiversity in the mountains, to document pollution in the fauna, to ecotoxicology, to capture genes, to do things like go to Chernobyl. Chernobyl has created a stressful environment. The mice that live there probably have genes that, if we can pull them out and use them, we probably can put them in cattle and every other thing and make a better cow that can live on a more stressful environment. We probably can get the plants there and get stuff that cotton can grow where there is more soil with salts and all kinds of things. I mean, everything is the good news and the bad news; you've just got to figure out what the good news and the bad news is. But this is the diamond in it. That's what it's about.

I remember a day when we were doing our survey in the mountains over on the west side, and I was trying to figure out where the limits of woodrats, *Neotoma mexicana* and *Neotoma albigula,* were. I had this idea that if we could figure out where that boundary was, and we could watch the stress on the system, maybe this would be a bioindicator of environmental stress and change, and we could follow this distribution, which one comes right up to the other. The west side is huge, you know. I mean, I was wandering around over there—you can only haul so many traps so long—so in the middle of this after a while I got to looking at these cacti, and I decided I didn't really care much about woodrats. I climbed that mountain all day long and I looked at probably a thousand of these cacti over there, and I got to looking at symmetry and everything else, and that actually was one of the finest days of my life. Then I saw the truth, went back, and started to set traps again.

The Guadalupe Mountains are an archive. Archive means to hold in trust. The Guadalupe Mountains are held in trust by the government and by us. You're the movers and the shakers. We are all a major part of this. What a diamond this lady is. What cake, icing and cake, this lady is. I think we need to not lose sight of the fact that we are in a position where we can impact this, and we need to dedicate ourselves to excellent science. We need to dedicate ourselves to biodiversity and ethics in behavior that will lead to and protect this. We need to dedicate ourselves to trying to spend the money because money is always going to be tight. There is never going to be enough that we can squander any. We need to make sure we spend it correctly and we need to go in with the same philosophy that we have heard so many times here, with the enthusiasm and the love and the pleasure that we get from the lady that is the Guadalupe Mountains. I hope all of this weaves together eventually so that we can do a better job, and I hope the Guadalupe Mountains are there for my children and my grandchildren and for all the other people that can appreciate those aesthetics.

Chapter 7

Interpreting Desert Regions, Deserts, and Regional Indicator Plants

FREDERICK R. GEHLBACH, Ph.D. of Baylor University has been a significant contributor to understanding the vegetation component of the Guadalupe Mountains and other Southwest desert regions. This paper was presented by Larry Henderson, superintendent of Guadalupe Mountains National Park.

I would like to talk about natural history and landscape interpretation in the National Park Service, or for that matter, in any organization committed to educating people about their natural heritage. My message is something I've been pushing for four decades—without much success I should add. It is simple and not entirely original, but traditions die hard and catchy words like "desertscrub" are easy to use even if incorrect. I will keep on trying because I see the public often confused by misleading or obscure terms, and even find educators confused on occasion, especially when it comes to desert plant communities versus desert regions, which is the focus of these remarks.

Because the goal of nature education—any education—is to facilitate self-learning, I advocate using descriptive names that permit easy recognition of Earth's plant cover. This requires common language and easily recognized terms with a long history of use, rather than new jargon. Vegetation is always present on the ground surface and therefore makes the best descriptor of living landscapes. Subjects like desert, grassland, woodland, and forest are easily visualized as are contrasting adjectives like shrub and succulent, lowland and upland, evergreen and deciduous. For example, I suggest speaking of lowland shrub versus upland succulent deserts.

Deserts, grasslands, woodlands, and forests (plant formations) of the United States and Mexico are present in all regions with topographic relief, including places that appear to be mostly comprised of desert. Thus, particular regions have been called deserts—Chihauhuan Desert, for instance—despite the obvious fact that they are not exclusively desert. Certain included areas may not even have desert, and hence the public is readily confused. I heard the Davis Mountains of Texas described as being "in the Chihuahuan Desert." I was with people who didn't see anything but plains grassland and evergreen woodland; they asked where the desert was. I told them that it didn't exist locally.

Chihuahuan is a regional adjective, defined by particular (indicator) plants with ranges centered in Chihuahua, Mexico. But some of these plants are not even desert species! In fact, the two main kinds of deserts present in the Chihuahuan region are identifiable elsewhere, in the Sonoran region, for example (Table 1). In low basins, widely spaced individuals of small-leaved shrubs indicate one kind—the lowland shrub desert; whereas in rocky uplands, clumps of succulent and semisucculent shrubs indicate the upland succulent desert. Soil and togography make the difference, although these deserts grade into one another over relatively smooth transitions in the landscape.

Tarbush in the lowlands and *Agave lechuguilla* in the uplands distinguish the two deserts in and near Chihuahua, just as white bursage and saguaro cactus denote these deserts in and near Sonora, Mexico (see Table 1). Yet, despite the regional differences in indicator species, lowland and upland deserts are structurally similar across regions, because there

	Lower Mountain Slope	Upper Bajada Slope	Lower Bajada-Basin	Arroyo (drainageway)
	4500 feet (1360 m)		3500 feet (1060 m)	
	Rock outcrops, rocks, crevices, little soil	Boulders, rocks, shallow soil	Small rocks, deep soil, caliche	Rocks, deep soil, subsurface water
	EVERGREEN WOODLAND	UPLAND DESERT	LOWLAND DESERT	DECIDUOUS WOODLAND
Life-forms	spaced oaks, junipers, evergreen sumac, basketgrass	clumped succulents, semisucculents, small-leaf shrubs,	spaced resinous or hairy, small-leaf shrubs	adjacent small-leaf, trees, shrubs along water course
CHIHUAHUAN REGION				
Indicators	**gray oak,** redberry juniper, foothill basketgrass	**lechuguilla, candelilla, slimleaf goldeneye,** ocotillo	**tarbush, ceniza,** creosotebush, whitethorn acacia	honey mesquite, desert hackberry, desert willow
SONORAN REGION				
indicators	blue oak, redberry juniper, foothill basketgrass	**saguaro, brittlebush, foothill paloverde,** ocotillo	**white bursage,** creosotebush	**ironwood**, honey mesquite, desert hackberry

Table 1. General vegetation profile on a topographic-edaphic gradient in the Chihuahuan and Sonoran regions. Plant formations in all-uppercase letters are named for structure and topographic position; representative life-forms and selected indicator species are given. Regional endemic indicator species are in boldface type; widespread indicators are in regular type.

are only a few ways of living in such a stressful environment as desert. In the present examples, plants conserve water by living apart from one another and having small protected leaves in low desert basins or by living together and storing water in modified leaves and stems in the rockier uplands.

Because many non-desert plants are also regionally specific, and desert life-forms are recognizable regardless of region, I omit the word “desert” in talking about Chihuahuan, Sonoran, Mohavean, and Great Basin regions. I only employ these adjectives for floristic geography—to specify the locations of particular species. That way I don’t have to deal with the confusion of missing deserts and can concentrate on adaptive features (lifestyles) and environments that help to understand particular local vegetation whatever it may be. (Locally, fine resolution is made by naming dominant species or co-dominants in associations, such as creosotebush-tarbush of the lowland shrub desert in the Chihuahuan Region).

Regardless of region, this interpretive scheme stresses the important reoccurring interaction between the distinctive dryness of deserts and plant features. It includes the special adaptation of form—features such as drought deciduousness, and small thick resin- or hair-protected leaves, by contrast to leaves capable of water storage regardless of region. Positioning is equally important to water conservation, hence the inter-regional similarity of spaced lowland plants, whether Chihauhuan regional creosotebush-tarbush or Sonoran regional creosotebush-bursage associations, by contrast to the clumping of upland Chihuahuan family groups of lechuguilla, similar to Sonoran saguaro-foothill paloverde nurse-plant assemblies (see Table 1).

What I’m saying about regions, regional indicator species, and deserts in landscapes with other plant formations is summarized in Table 1, which compares a topographic gradient in the Chihuahuan region with its counterpart in the Sonoran. Representative life- and growth forms typical of each vegetation type and selected regional indicators plus widespread species are given together with general notes on soil conditions and elevations. Table 1 does not mention special plant associations on localized soils, such as gypsum or quartz sand, but these usually represent the lowland shrub desert.

Selected references

I offer a few exemplary references with brief notes on their contents, as they relate to my subject and to the natural history interpretation of Guadalupe Mountains National Park. All of these contain useful and important information, but nearly all use the epithet, “Chihuahuan Desert,” to describe one or both interregional deserts without alluding to regional indicators. Some also use the misleading word, desertscrub, which specifies that deserts are scrubby (unable to attain mature stature). This is untrue in undisturbed situations.

Brown, D. E., editor. 1982. Biotic communities of the American Southwest–United States and Mexico. Desert Plants 4:1–342. Useful comprehensive treatment that puts a nice perspective on southwestern and Mexican vegetation patterns. Authors use the misguided term, desertscrub, and Chihuahuan, Sonoran, etc. are employed as adjectives for desert vegetation.

Brown, D. E., F. Reichenbacher, and S. E. Franson. 1998. A classification of North American biotic communities. University of Utah Press. Salt Lake City. An updated reference with nice photographs but employing confusing and misleading terms as in Brown (l982).

Burgess, T. L. and D. K. Northington. 1977. Desert vegetation in the Guadalupe Mountains region. Pages 229–242 in R. H. Wauer and D. H. Riskind, editors. Symposium on the biological resources of the Chihuahuan Desert region, United States and Mexico. Transactions and Proceeding Series number 3. National Park Service, Washington, D.C. Provides a useful breakdown of plant life-forms on quartz and gypsum sands but does not provide comparisons with other soils. The authors employ Chihuahuan Desert and desert-scrub (note hyphenated).

Dick-Peddie, W. A. 1993. New Mexico vegetation: past, present, and future. University of New Mexico Press. Albuquerque. Fine general area reference but compounds interpretive confusion by employing the novel epithet, Chihuahuan desert scrub. Deserts are mapped in the Guadalupe region, generally occurring at lowest elevations below desert or plains grassland which is below evergreen woodland. If overgrazed and lacking periodic fire, grassland can be desertified as it has been in the Guadalupe region.

Gehlbach, F. R. 1967. Vegetation of the Guadalupe escarpment, New Mexico–Texas. Ecology 48:404–419. Only quantitative study of the Guadalupe Mountains vegetation-types. Describes lowland (small-leaved shrub) and upland (succulent, semisucculent) deserts, and introduces the present system of naming vegetation on the basis of life-forms and/or topographic positions using unbiased quantitative appraisals of measured plant cover.

Gehlbach, F. R. 1979. Biomes of the Guadalupe Escarpment: vegetation, lizards, and human impact. Pages 427–439 in H. H. Genoways and R. J. Baker, editors. Biological investigations in the Guadalupe Mountains National Park, Texas. Proceedings of a symposium held at Texas Tech University, Lubbock, Texas. Transactions and Proceedings Series number 4. National Park Service, Washington, D.C. Why and how landscape may be interpreted to the public based on vegetation, lizards, and human impacts, the sum of which is more comprehensive (ecosystemic) than vegetation alone.

Gehlbach, F. R. 1981. Mountain islands and desert seas: a natural history of the U.S.–Mexican borderlands. 1st edition. Texas A & M University Press, College Station. The first chapter describes the present vegetation and regional interpretive system, which is used throughout the book.

Johnston, M. C. 1977. Brief resume of botanical, including vegetational, features of the Chihuahuan Desert region with special emphasis on their uniqueness. Pages 335–359 in R. H. Wauer and D. H. Riskind, editors. Symposium on the biological resources of the Chihuahuan Desert region, United States and Mexico. Transactions and Proceedings Series number 3. National Park Service. Washington, D.C. Reviews regional indicator species including endemics from vegetation-types besides deserts, yet uses Chihuahuan Desert region.

Johnston, M. C. 1979. The Guadalupe Mountains: a chink in the mosaic of the Chihuahuan Desert? Pages 45–49 in H. H. Genoways and R. J. Baker, editors. Biological investigations in the Guadalupe Mountains National Park, Texas. Proceedings of a symposium held at Texas Tech University, Lubbock, Texas. Transactions and Proceedings Series number 4. National Park Service, Washington, D.C. Despite the misleading title, this text is specifically but briefly about the Chihuahuan regional flora. It is about the only recent unambiguous interpretive treatment of the Chihuahuan regional concept.

Northington, D. K., and T. L. Burgess. 1979. Summary of the vegetative zones of the Guadalupe Mountains National Park, Texas. Pages 51–57 in H. H. Genoways and R. J. Baker, editors. 1979. Biological investigations in the Guadalupe Mountains National Park, Texas. Proceedings of a symposium held at Texas Tech University, Lubbock, Texas. Transactions and Proceedings Series number 4. National Park Service, Washington, D.C. Usefully compares plant ecological terms but uses desertscrub and says the park is transitional between Chihuahuan Desert and plains grassland, confounding interpretation by comparing a region (Chihuahuan) and within-region vegetation (plains grassland).

Chapter 8

Recent Changes in the Breeding Avifauna of Four Southwestern Mountain Ranges in Texas and Coahuila

KELLY B. BRYAN has been the Regional Resource Coordinator for the Texas Parks and Wildlife Department for the past 17 years. He has participated in past Christmas bird counts at the park and is interested in the continued documentation of changes to the breeding avifauna to the park and its relationship to the same of other mountain islands in the southwestern United States.

Today I am going to talk about the changes in the breeding avifauna of four southwestern mountain ranges. This first appeared in the symposium of the Chihuahuan Desert Research Institute back in 1974, in a publication by Ro Wauer and David Ligon that tried to chronicle which birds nested in montane habitat. At that time they defined the montane habitat as elevations over 5,500 feet. I have taken the information that they presented and followed it through today, and I am going to try to chronicle some of the changes. What precipitated my interest in these mountain islands was the fact that in 1990 Steve Howell and Sophie Webb recorded four or five species of birds on a piece of property in the Davis Mountains that were not known to be nesters in Texas. This opened a door of opportunity in 1991 for a survey in June that followed up through about mid- 1992 with some survey work in the Davis Mountains. Most of the information that I am presenting today concerns the Davis Mountains, and I am going to show you a short slide program of what the habitat looks like up there. We will look at the table that Wauer and Ligon presented in 1974 and at the changes that have occurred based on new knowledge, new discoveries, and things that we have located in the Davis Mountains, as well as what we know of some of the changes in the Guadalupe Mountains. So, without any further ado, I will start the slides.

This is the south rim trail in the Chisos Mountains. I thought I would throw in a few slides of the Chisos Mountains, for those of you who don't know these three mountain islands. I'm not going to talk much about the Sierra del Carmen in Mexico, but [these photos of] the Chisos Mountains will show you the habitat and what is up there. This view is from the south rim, looking down toward Santa Elena Canyon, down near Castolon, Boot Canyon. The mountain island there is very restrictive—only about 10 square miles—but the habitat diversity is very broad. The plant diversity is probably greater in the Chisos Mountains than in the Davis Mountains, [and] might rival what diversity there is in the Guadalupes. This is Boot Canyon—the type of montane forests that you would have at elevations of 5,500 feet high and higher in the Chisos Mountains. You have Arizona cypress there, which is one plant represented that is not present in either the Davis or the Guadalupes. Just a few more habitat shots: down in lower Boot Canyon, you get kind of an oak canopy forest, but you have quite a bit of diversity there on the floor of the forest in the form of shrubs. You will see that there is not a heck of a lot of grass coverage on the floor of the forest in the Chisos.

Let's go to the Guadalupe Mountains. The substrate in the Chisos was igneous. The dominant substrate here is obviously limestone. You have heard a lot about the geology. Here are some pictures of the Guadalupe Mountains. Going up McKittrick Canyon, you get a little bit more hardwood diversity, approaching elevations of 5,500 feet. You go a little bit higher, and you get piñon and juniper woodlands, with not very much hardwood diversity, I discovered yesterday. The mountain chain here is very much a linear mountain range. It is a very rugged mountain range with deep canyons; it really differs considerably from the Davis Mountains, which I will show you in just a second. You get fairly well developed grassland for ground cover in these areas, especially areas where fires have been able to burn freely.

Now the Davis Mountains—I know more about the Davis Mountains than I do the Guadalupe Mountains, and we have been able to do some surveys. All of our surveys there have been conducted on lands that we have had permission to go on, private lands prior to this year, and the bulk of the central portion of the mountain range is now owned by the Nature Conservancy of Texas, and is called the Livermore Preserve. In the future we will be making further investigations into the avifauna of that area, especially with an emphasis on the breeding avifauna.

This is a picture from Davis Mountains State Park, near Fort Davis. The elevation where I am standing is about 5,600 feet, so it is above 5,500 feet elevation. This is Limpia Canyon, and you see kind of the southern end of the Davis Mountains range, including the most significant peaks. This is Paradise Ridge here. You see Mount Livermore; it has that little knobby peak on the end, called Old Baldy or Baldy Peak. That is Mount Livermore, and then Madera Canyon would be over the ridge here, and on the other side of that ridge would be the core of the Livermore Preserve in Madera Canyon, and I'll show you that in just a minute. From the air, this is the south slope of Livermore. You'll see that even though it has these nice, rugged igneous outcrops, providing a lot of vertical cliff habitat for things like prairie falcons and white-throated swifts, violet-green swallows, etc., it doesn't have nearly the rugged nature that the Guadalupes do. The south slope of the mountains is fairly dry. There are very few tall pines. There are some pines in these enclaves here, which are wetter [and] more mesic, as you get to the north side. Let's just go to the other side of Livermore and look at it from the north slope. The upper Madera Canyon is very wooded with very thick forest and lots of tall pines, both *Pinus ponderosa* and *Pinus strobiformis*, the southwestern white pine; this is all upper Madera Canyon at this point. From the mountain, this is what Madera Canyon looks like, when you look down. This is a view to the north and northwest from the road leading up to the summit of Mount Livermore. You can still see that the largest pines are found in the more mesic zones, the drainages. The drier slopes are covered with piñon and juniper woodlands only. There are very few ponderosas. The forest is well-developed there and has never been logged, but you will see that the ground cover is still grassland. The shrub component of the forest is basically absent in the Davis Mountains; there is just not very much shrub diversity. The midstory would be alligator juniper and various oaks, but it is a very dynamic woodland, based on the avifauna that are located there, especially in the breeding season. Fire still has a free rein in the mountains and burns through on the ground. It sometimes gets fairly fierce. In 1993 a fire was started by lightning in the canyon, and it burned about 26,000 acres over 12 days; it was suppressed by the Texas Forest Service, local volunteers, etc. There was also a very large fire of about 25,000 acres that occurred in the late 1970s—I think 1977 or 1978. So to a certain extent fire still does control the ecology of the area.

The north slope of Mount Livermore is certainly the most interesting, habitat-wise; therefore, from an avifaunal aspect, it is also the most interesting. This is what the north-slope woodlands look like. It is basically on a fairly steep incline—maybe a 30° at the minimum. There is a lot of southwestern white pine and ponderosa pine. Gambel oak is the main oak component of that forest. You can still see on the ground; there are basically grasses and a few minor shrubs.

The mountain snowberry is fairly common in places there. We found a painted redstart nest on this slope right here, which is the first record ever for that species in the Davis Mountains. There was a nest with young. I will show you a picture of a painted redstart in a minute. Just above that slope aspect, there is a real nice stand of quaking aspen. There are probably a half-dozen or so stands of aspen on Livermore; some of them are fairly extensive, but they are usually in the very mesic enclaves, rock breakdown, or talus slope type situations. This August [1997] in this particular woodland, a bird was added to the Texas list. Greg Lasley, John Karges, and a couple other folks were fortunate to be there and get pictures of a slate-throated redstart that was in this aspen stand, which was the first confirmed record for Texas.

This is that north-slope woodland, of which I showed you three pictures earlier. You can see the big pine. There are the aspens—a fairly extensive stand. There is the summit of Livermore right above there, so you're at about 8,000 feet, maybe just below 8,000 feet at this location. And because it's been private land and a working ranch for many, many years, you find a lot of situations like this. You find basically what we call stock ponds up in the forest habitat. Most of these stock ponds have good water resources in them. It is pretty dry right now. In Fort Davis, we have had less than two-tenths of an inch of rain in four months. Livermore and the foothills of the mountains are extremely dry right now. This would be a fairly typical situation on an average year, as far as rainfall. We walked into this woodland and found a pair of common black-hawks sitting on the shore of this particular pond, which is probably up at very near 7,000 feet elevation, or just below. You can see well-developed ponderosa woodland, and nobody has ever located Douglas-fir in the mountains.

Let's talk about some of the birds, just briefly introduce them. Sophie Webb and Steve Howell located a gray flycatcher, *Empidonax wrightii*, in 1990 carrying nesting material. The nearest nesting gray flycatchers were in south-central New Mexico some 250 to 300 miles north of the Davis Mountains; therefore, it was thought to be very improbable that the gray flycatcher might be represented as a breeding bird. Here is a male on territory. Here is a female with food in her mouth headed to a nest. This picture, taken in June 1991, represents the first nesting record for Texas. During the surveys in June 1991 and the follow-up surveys in 1992, we easily documented an excess of 30 pairs or 30 territories of *Empidonax wrightii* in Madera Canyon, which I think is a very significant population of a species that is disjunct from its core population by 250 to 300 [miles]. So the gray flycatcher is a definite addition to the breeding avifauna of the range.

Some other things that we found up there—I don't know how many of you recognize this—is a bird of the Sierra Madre Occidental that just barely gets into the Animas Range in New Mexico and southeastern Arizona mountain islands. That picture really shows well its name "dusky-capped flycatcher." It is a Myiarchus flycatcher that is of Mexican origin, Madrean origin. Here is another picture of it. These pictures were taken on our surveys in 1991, and in 1992 we had no less than seven birds, including three pairs, but were not able to confirm nesting, because of access problems in mid-1992. This would be one species that you will see. I have got a table up here that I have produced for these four mountain islands that you can pick up (see Table 1). This will be one bird that I think will be a target to confirm is nesting in Texas. It is even more disjunct from its core population, maybe by excess of 300 miles in Chihuahua. So the dusky-capped flycatcher will be a bird that will be represented perhaps as a breeding bird there that is not represented in any of the other four mountain islands that were characterized in that treatise by Wauer and Ligon.

Here is a picture of a painted redstart. This is not the pair that nested there, but wanted to throw it in to show you. I think it's pretty significant that we found painted redstart there on the north slope woodland, because it was previously

Table 1. Differences in the breeding avifauna of four southwestern mountain ranges in Texas and Mexico (for elevations above 5,500 ft). ©1995, Kelly B. Bryan and John P. Karges (version 3/1/2001). Based on Wauer and Ligon 1974. Trans. of the symposium on the biological resources of the Chihuahuan Desert region. Shaded blocks indicate species added and/or status changes since 1974. * indicates marginal species normally breeding at lower elevations. ® indicates species normally breeding exclusively above the designated elevation.

	GUAD	DAVIS	CHISOS	CARMEN
TURKEY VULTURE	X	X	X	X
SHARP-SHINNED HAWK®	R	R	R	X
COOPER'S HAWK	X	X		X
NORTHERN GOSHAWK®				X
COMMON BLACK-HAWK*		X		X
ZONE-TAILED HAWK	P	X	X	X
RED-TAILED HAWK*	X	X	X	X
GOLDEN EAGLE	X	X	X	X
AMERICAN KESTREL	X	X	X	X
PRAIRIE FALCON®	R	X	R	
PEREGRINE FALCON	X	H	X	X
MONTEZUMA QUAIL	P	X	H	X
WILD TURKEY	X	X		X
BAND-TAILED PIGEON®	X	X	X	X
WHITE-WINGED DOVE*	P	X	X	X
MOURNING DOVE	X	X	X	X
YELLOW-BILLED CUCKOO*		P		
GREATER ROADRUNNER*	X	X	R	?
FLAMMULATED OWL®	X	X	X	X
WESTERN SCREECH-OWL	X	X	X	X
GREAT HORNED OWL	X	X	X	X
NORTHERN PYGMY OWL®				X
ELF OWL*	R	R	X	X
SPOTTED OWL®	X	R		
NORTHERN SAW-WHET OWL®	X	P		X
COMMON NIGHTHAWK	X	X		X
COMMON POORWILL	X	X	X	X
WHIP-POOR-WILL®	X	X	X	X
WHITE-THROATED SWIFT	X	X	X	X
WHITE-EARED HUMMINGBIRD®		?		P
BLUE-THROATED HUMMINGBIRD®	R	?	X	X
MAGNIFICENT HUMMINGBIRD®	X	X	X	X
LUCIFER HUMMINGBIRD		P	X	X
BLACK-CHINNED HUMMINGBIRD	X	X	X	X
BROAD-TAILED HUMMINGBIRD®	X	X	X	X
ACORN WOODPECKER	X	X	X	X
LADDER-BACKED WOODPECKER	X	X	X	X
HAIRY WOODPECKER®	X			P
NORTHERN FLICKER	X	X	X	X
OLIVE-SIDED FLYCATCHER®	X	?		
WESTERN WOOD-PEWEE	X	X		?
DUSKY FLYCATCHER®	?	X		
GRAY FLYCATCHER®	?	X		
CORDILLERAN FLYCATCHER®	X	X	X	X
BUFF-BREASTED FLYCATCHER		R		
BLACK PHOEBE	X	X	X	X
SAY'S PHOEBE	X	X	X	X
DUSKY-CAPPED FLYCATCHER®		P	R	
ASH-THROATED FLYCATCHER	X	X	X	X
CASSIN'S KINGBIRD	X	X		
VIOLET-GREEN SWALLOW®	X	X	X	X
BARN SWALLOW*	X	X	X	
STELLER'S JAY®	X	X		
WESTERN SCRUB-JAY	X	X	R	
MEXICAN JAY®			X	X

	GUAD	DAVIS	CHISOS	CARMEN
COMMON RAVEN	X	X	X	X
MOUNTAIN CHICKADEE®	X	X		
JUNIPER TITMOUSE*	X			
"BLACK-CRESTED" TITMOUSE		X	X	X
BUSHTIT	X	X	X	X
RED-BREASTED NUTHATCH®	R			
WHITE-BREASTED NUTHATCH	X	X	X	X
PYGMY NUTHATCH®	X	X		X
BROWN CREEPER®	X	?		
CACTUS WREN*	X	X	X	X
ROCK WREN	X	X	X	X
CANYON WREN	X	X	X	X
BEWICK'S WREN	X	X	X	X
HOUSE WREN®	X	X		X
BLUE-GRAY GNATCATCHER	X		X	X
WESTERN BLUEBIRD®	X	X		X
MOUNTAIN BLUEBIRD®		R		
TOWNSEND'S SOLITAIRE®				P
HERMIT THRUSH®	X	X		
AMERICAN ROBIN	X	X		X
NORTHERN MOCKINGBIRD*	X	X	X	X
CURVE-BILLED THRASHER	X	X	R	X
CRISSAL THRASHER*	R	?	X	X
PHAINOPEPLA*	R	X	R	P
LOGGERHEAD SHRIKE*	X	X	?	?
BLACK-CAPPED VIREO*			X	X
GRAY VIREO	X		X	X
PLUMBEOUS VIREO®	X	X	H	X
HUTTON'S VIREO®	X	X	X	X
WARBLING VIREO	X	X	H	
ORANGE-CROWNED WARBLER®	X	X		
VIRGINIA'S WARBLER®	X	X		
COLIMA WARBLER®		P	X	X
"AUDUBON'S" WARBLER®	X	X		
BLACK-THROATED GRAY WARBLER®	H			
GRACE'S WARBLER®	X	X		
MacGILLIVRAY'S WARBLER®		?		
PAINTED REDSTART®		R	R	X
SLATE-THROATED REDSTART®				X
OLIVE WARBLER®				X
HEPATIC TANAGER®	X	X	X	X
WESTERN TANAGER®	X	X		
BLACK-HEADED GROSBEAK	X	X	X	X
BLUE GROSBEAK*	X	X	X	X
GREEN-TAILED TOWHEE®	X	X	H	?
SPOTTED TOWHEE®	X	X	X	X
CANYON TOWHEE*	X	X	X	X
CASSIN'S SPARROW*		X		
RUFOUS-CROWNED SPARROW	X	X	X	X
CHIPPING SPARROW	X	X		
BLACK-CHINNED SPARROW	X	X	X	X
LARK SPARROW*	X	X		?
"GRAY-HEADED" JUNCO®	X			
YELLOW-EYED JUNCO®				X

	GUAD	DAVIS	CHISOS	CARMEN
EASTERN MEADOWLARK	X	X		
BREWER'S BLACKBIRD		R		
BRONZED COWBIRD*		X	?	?
BROWN-HEADED COWBIRD	X	X	X	X
AUDUBON'S ORIOLE				X
SCOTT'S ORIOLE	X	X	X	X
HOUSE FINCH	X	X	X	X
RED CROSSBILL®	X	R		?
PINE SISKIN®	X	R		P
LESSER GOLDFINCH	X	X	X	X
REGULAR NESTER (X)	83	82	57	76
RARE/LOCAL NESTER (R)	7	9	8	0
PROBABLE NESTER (P)	3	5	0	4
POSSIBLE NESTER (?)	2	6	2	7
HISTORICAL NESTER (H: PRIOR TO 1974)	1	1	4	0
TOTAL KNOWN/POTENTIAL BREEDERS	96	103	71	87

thought that the Chisos Mountains represented the northern extent of nesting painted redstarts. In fact, in 1992 when this bird was nesting in the Davis Mountains, there wasn't a single pair documented as nesting in the Chisos. I think that's pretty significant in that the nearest nesting painted redstarts to the pair that were in the Davis Mountains that particular summer had to be in the Sierra del Carmen of Coahuila, Mexico, where it's a very common bird and a regular nester. So the painted redstart was an unexpected discovery for the breeding contingent there.

Another unexpected bird was the northern saw-whet owl. Mark Lockwood photographed this bird in 1991 near the top on Paradise Mountain, and we found it both in 1991 and 1992. We think it's going to be a fairly regular summer component of the breeding avifauna, but we need to confirm it as nesting. Even though we have recorded northern saw-whet owl in the summertime, it will be on the table as a probable nester instead of being confirmed as a nester. David Woolf, by the way, had one here in the Guadalupes, I think about a month and a half ago; it was calling on territory, and he got recordings off of it.

A bird that was not listed previously by Wauer and Ligon was the red crossbill. I photographed this bird along with a second juvenile and a female—both juveniles were begging for food—at the McDonald Observatory in the summer of 1995, I believe. An obvious juvenile red crossbill, mid-July record, indicates that those birds had to have fledged from a nest nearby. So, red crossbill is added as a breeding component of the Davis Mountains. It had always been a component of the Guadalupe Mountains.

One of the biggest surprises we had was the discovery of almost an annual population of white-eared hummingbirds in the Davis Mountains. This particular adult female was at a feeder in 1993 in upper Limpia Canyon, and the birds are present from May through September. It is one of the three birds that were present that particular summer. In June, this bird right here, which is a juvenile male characterized by the sandy color at the lore, but look at the breast; it's not even fully feathered. I have shown this to a lot of folks, and if you want to vote on it, you can. I think this bird had to be reared locally. How could a bird with a not even fully feathered breast, a juvenile white-eared hummingbird, fly approximately 300 miles from the nearest known nesting locality to the Davis Mountains and spend June through September at that location? Birds showed up in May. I think there's a small nesting contingent, but it needs to be confirmed. This would be one of the things we're looking for.

This year we added another bird to the Texas State list. A Berylline hummingbird was present for about three weeks in August at feeders in upper Limpia Canyon; this bird is thought to be an adult female. There had been one previous sight record, but unconfirmed, and so the pictures that you see here, taken in August, were the first confirmed records from Texas.

I have been fortunate to be in the right spot in 1992 on Mount Livermore on another occasion. This spring singing male olive warbler was a first confirmed record for Texas. There had been maybe three or four viable sight records but no confirmation prior to May 1992, and this picture represents the first confirmed record for Texas. So Mount Livermore and the Davis Mountains have a lot of discoveries yet to be made, and we would be real fortunate to be a part of looking at some of the avifaunal components year round.

Here's a pretty picture of Montezuma quail. There's still a very strong, viable population in the Davis Mountains, but it has totally disappeared from the Chisos, and now I understand it has probably disappeared from the Guadalupes. It used to be a native component of the avifauna here in the Guadalupes, and it was subject to reintroduction programs, I think both in the Chisos Mountains and in the Guadalupe Mountains, and it doesn't look like these populations are going to hang on. [Note: Montezuma quail have been periodically but infrequently seen in the Dog Canyon area almost every year since the 1986 reintroduction project.] I can say one thing, that studies on the Montezuma quail have indicated that they are not a bird of short grasslands, and they must have medium to tall grasslands and a fairly good coverage on the land in order to have a good viable population. So if grazing is a problem, such as on federal lands, it might reduce the grassland to an extent of coverage that the Montezuma quail cannot tolerate. There are still good viable grasslands in the Davis Mountains, and I think that's the reason the population is so viable there.

This will end the slides, and I will go into some more detail. I just want to show a nice sunset in the ponderosas of Ridge Gap near Mount Livermore, and even though the sun sets every day, we are just beginning, I think, the chapter of bird discoveries in the Davis Mountains. Now that private lands have been purchased by the Nature Conservatory of Texas, there may be some opportunities at some point in the future to do further studies. I would be really pleased to be a part of that study team, and we have a lot more discoveries to make. We've got a lot of things to fill in from our brief surveys in 1991 and 1992. I don't know the Guadalupes really well, but I want to present some information based on Wauer and Ligon's table for the Davis Mountains and the Guadalupe Mountains.

It's been about 25 years since Wauer and Ligon did their study. At that time their publication in 1974 listed 83 species for the Guadalupe Mountains as birds breeding, above 5,500 feet of elevation. They had 81 regular nesters and two probable nesters. The Davis Mountains were listed as having 72 species regular and two probable. The Chisos Mountains had 64 regular nesters. They didn't list any birds at that time that were just probable in occurrence as a nesting bird. Sierra del Carmen in Mexico listed 73 regular breeding species with two probable. I thought I'd go over some of the comparisons of the mountain islands so that you would understand a little bit of the differences there. Maximum elevation of the Guadalupe Mountains is around 8,750 feet. The area of the mountain island that exists above 5,500 feet is listed by Wauer and Ligon as 65 square miles. Now, I think that needs to be defined, because I don't know whether they included all of the [Guadalupe Mountains] area in New Mexico. The title of the presentation should include the state of New Mexico, because the Guadalupe Mountains don't stop at the political boundary of the national park or the state line of Texas. Therefore, it needs to be extended north into New Mexico, and it certainly would encompass, I think, some diversity of habitats that aren't well represented in the park. I am going to reflect on that in just a minute. Again, the substrate is limestone.

The Davis Mountains maximum elevation is about 8,350 feet above sea level. Now, here's a big thing. Wauer and Ligon listed the area above 5,500 feet as being 70 square miles. Now, think about that. It's the most massive mountain range in Texas. I got to thinking about that myself and I pulled out topographic maps and started looking at it, and Jeff Davis County is 2,254 square miles. If the Davis Mountains with elevations in excess of 5,500 feet covered only 70 square miles, that would be less than 3% of the area of Jeff Davis County. No way. So we got to looking at the information. Fort Davis itself is right at 5,000 feet elevation, and the state park has a lot of elevation in it in excess of 5,500 feet. I discovered there was probably a decimal place there in the calculation, and instead of being 70 square miles it was likely 700 square miles. I confirmed that by examining the 5,500-foot line on the topographic map. I think it's actually closer to 650 square miles in excess of 5,500 feet of elevation, which would make it right at one-third of Jeff Davis County. All of that 5,500-foot elevation contour line is in Jeff Davis County except for a small contingent in northwestern Brewster County. None of it lies in Presidio County whatsoever. So it's 650 square miles, which changes things quite a bit. You're going to see that reflected in the numbers in just a minute.

The Chisos Mountains remain at a maximum elevation of about 7,835 feet with 10 square miles above 5,500. Their basic substrate is igneous. In the del Carmen Mountains in Mexico, you get two [substrates]. You get the northern Sierra del Carmen, which are all a limestone substrate with several peaks in the neighborhood of 8,000 feet, but the southern section of the mountain known as the Sierra de la Encantata, is going to be all the way up to 8,960 in elevation, Lumas Peak, and it has an igneous substrate. So the Sierra del Carmen is kind of a dual type of mountain there. Both are listed as having elevations covering an area of 115 square miles above 5,500 feet elevation. I don't know what the exact breakdown is between the igneous part of the mountain and the limestone part of the mountain, but that's what is listed.

Before we analyze some of the changes in the birds, I thought it might be interesting for you to learn some of the vegetation changes that have been applied to these ranges. Just dealing with the dominant woody species: ponderosa pines were previously listed for all four mountains, but now it's on the Davis and Guadalupe mountains only. Ponderosa pine is not found in the Chisos and not found in the del Carmen. In the Chisos, the pine is described as being *Pinus arizonica* var. *stormiae*, and it's called the Arizona pine, which is different now taxonomically than the ponderosa. In the del Carmen you have both Apache pine, *Pinus engelmanni*, and the Chihuahua pine, *Pinus leiophylla*. So there are no ponderosas in the del Carmen, either. You have southwestern white pine in the Davis Mountains, basically no change from the previous table that's listed for Guadalupes, Davis, and del Carmen mountains. There is no change in firs. You have a couple of firs, I think, in the del Carmen; Douglas-fir is in the Guadalupes and a little bit in the Chisos. It's just a very minor component of the woodland. There are absolutely no fir whatsoever in the Davis Mountains. There is no change in Arizona cypress. It's only found in the Chisos and the del Carmen. With the junipers you have some changes. No change with respect to alligator juniper found in all four, but you now have Rocky Mountain juniper, *Juniperus scopulorum*, in the Guadalupes, and the juniper in the Davis Mountains is now known as *Juniperus erythrocarpa*, rose-fruited juniper. It's only represented in the Davis Mountains of these four mountain islands, I think. It may be in the del Carmen, though. *Juniperus monosperma*, or one-seed juniper, which was previously listed for all four, is now just found in the Guadalupes. Oaks: there are basically four oaks in the Guadalupes, eight oaks in the Davis Mountains, eight oaks in the Chisos Mountains, and nine oaks in the del Carmens.

What have we found in the Davis Mountains? First of all, from [Wauer and Ligon's] table, I deleted yellow- billed cuckoo, because I do not believe it occurs anywhere in any of these mountain islands and in elevations in excess of 5,500 feet. Birds that were listed as probable previously in the Davis Mountains, which are now confirmed as regular nesters, would include magnificent hummingbird and western tanager. Birds that were not listed previously which are now considered regular nesters include common black-hawk, white-winged dove, greater roadrunner in the inner montane and montane islands of grassland, the gray flycatcher, black phoebe which nests up high as well, and barn swallow. Anywhere you have a ranch up high, above 5,500 feet in elevation, you're going to get barn swallows. I suspect that they are probably here in the Guadalupes in that same respect. House wren was not listed previously for the Davis Mountains. It's common in rock outcrops and downed timber areas at elevations in excess of 7,800 feet. American robin was not listed previously. It's found in Madera Canyon, all up and down the canyon, and has also nested in Fort Davis itself; that's not above 5,500 feet, though. Loggerhead shrike is up there in the high mountain meadows. Near the summit of Livermore, we found orange-crowned warblers on nest and Virginia's warbler, which is the second most abundant warbler to Grace's. Grace's is the most common warbler up there as a nesting bird. Also, Audubon's warbler, of which I think there was some previous information that should have had them listed as probable, but Audubon's warbler is there as well. Green-tailed towhee and black-chinned sparrows both nest in stunted oaks at the summit of Livermore, so green-tailed towhee is new to the list. Lark sparrow in the inner montane meadows and bronze cowbird now has been found up high in the mountains.

Birds changed from those not listed to those that would be historical are those for which we don't have any definitive evidence in the last 25 years still nest in the Davis Mountains. Spotted owl: Steve Runnels of the Dallas Museum documented nesting spotted owls in the late 1970s in the Davis Mountains, and we do have one recent record which would indicate probably resident birds and the probability that they are still there as nesters. Mountain bluebird: the first nesting record for Texas was obtained by me, Barry Zimmer, and Victor Emanuel two years ago on the south end of the Davis Mountains, so mountain bluebird has been added. Others include painted redstart and red crossbill.

The birds that were previously not listed that are probable nesters are the birds that we will need to work on. These are the northern saw-whet owl, the olive-sided flycatcher, which is a probable nester up high as well, and the dusky-capped flycatcher.

Those birds changed from not listed to possible nesters are the birds that have been present, and we need to look at. We don't know what the exact extent for sharp-shinned hawk, northern pygmy owl, white-eared hummingbird, and blue-throated hummingbird. Lucifer hummingbird is there every year now and probably is nesting. Brown creeper and MacGillivray's warbler are possible nesters.

Birds on the table changed from regular to historical are those birds that we don't have any evidence in 25 years that they've nested: peregrine falcon and Brewer's blackbird. There's only one [Brewer's blackbird] nesting record, and Pansy Espey found that in Madera Canyon about 25 years ago.

We downgraded some birds from a regular nester to a rare and local nester including elf owl and pine siskin. Also, birds I suspect that are not in the mountains would be blue-gray gnatcatcher, which we can't find anywhere in the range; crissal thrasher as a nester, it's a winter bird but not a nester; and gray vireo. Also, we're close to deleting summer tanager from the birds that nest in the Davis Mountains.

I compared the [table with the current] checklist of the Guadalupe Mountains, which really doesn't include the area in New Mexico, a portion of the Guadalupe Mountains range. You will see some of the discrepancies there that probably need to be confirmed and checked. I think the breeding avifauna is the most important aspect of the birds that occur in any location, especially in parks. Therefore, it behooves us as resource managers to really get a handle on those birds that breed or nest within the boundaries of your jurisdiction. So you'll see some discrepancies there. I'm probably going to downgrade sharp-shinned hawk to rare in the Guadalupes. Zone-tailed hawk is not listed as a nester in the checklist, but it's probably a rare and local nester. There are some Montezuma quail. Also, northern pygmy owl is not listed as a nester. Common nighthawk is not listed as a nester, but it was listed previously by Wauer and Ligon and is probably present. You will see some others. Dusky and gray flycatchers are two Empidonax flycatchers that need to be really investigated. So these would be two species that should be looked at in further detail if they are present in the summertime. Again, common raven is not listed as a nester; I don't know why. I think some of these birds that I listed as "Elevation?" after seeing the New Mexico section of the Guadalupe Mountains and up in Dog Canyon, we can easily put on the list because some of those inner mountain grassland species like Lillian's or eastern meadowlark, lark sparrow, roadrunner, loggerhead shrike are all there, and they're all above 5,500 feet as nesters.

Thank you very much.

Chapter 9

Avifaunal changes in the Guadalupe Mountains of New Mexico and Texas

STEVE WEST is a local biological sciences instructor and is the principal investigator of the longest-running data sets on cave swallow at Carlsbad Caverns National Park. He is active with projects for the Chihuahuan Desert Conservation Alliance and the Nature Conservancy.

The Guadalupe Mountains of west Texas and southeastern New Mexico are one of the many "sky islands" located in the American Southwest and northern Mexico. Sky islands are isolated mountain ranges surrounded by hot, dry lowlands, usually desert grassland or scrub areas. The uniqueness and importance of these areas have long been recognized, and they usually have a higher degree of biodiversity than surrounding areas. This richer flora and fauna can be attributed to three factors. One is the sky islands have a variety of habitats. Another factor is that many of them are isolated biologically from similar areas, and endemic species develop. A final factor is that relict populations are often found from pre-Holocene times when climates were different and isolation occurred to a lesser degree. The biodiversity of the Guadalupe Mountains is a result of all these factors.

This paper examines the avifauna of the Guadalupes, starting with what we know of populations around the turn of the 20th century, changes during the 20th century, and what we might expect over the next century.

The Guadalupe Mountains extend in a general southeast to northwest direction, losing elevation as one proceeds to the northwest. The general area at its greatest length is about 55 miles (80 km) and at its widest is a little less than 36 miles (60 km). The mountain range occurs across several political boundaries and occupies parts of two states and five counties. In part because of this, land management schemes have differed widely in the Guadalupes, ranging from high to low degrees of protection and activity.

The high point in the mountains is Guadalupe Peak at 8,749 feet (2,667 m). The low point is not as easy to determine because of defining where in the transition area the Guadalupes stop and start. For the purposes of this paper, the low point would be around 3,500 feet (1,067 m) along the eastern edge of the escarpment in the area of Carlsbad. In this paper all of the land within the Guadalupe Mountains unit of the Lincoln National Forest, Carlsbad Caverns National Park, and Guadalupe Mountains National Park is included. This is a large area of about 408,840 acres (164,455 ha). Compared with other areas, it is a little more than half the size of Big Bend National Park in west Texas, an area long recognized for a very diverse avifauna with about 450 species.

Currently about 363 species representing 55 different families have been reported from the Guadalupes. Carlsbad Caverns National Park with 337 species has the richest list followed by Guadalupe Mountains National Park with 295. The Lincoln National Forest unit has 166 species. The low number of species recorded from the forest is more a reflection of a lack of field work there than an indication of species paucity. While much of the Lincoln National Forest may appear to differ little, there are places such as Big Canyon which are probably as rich biologically as anyplace in the range. The numbers listed for each of the units differs somewhat from checklists currently in use because of recent taxonomic revisions. In addition, species which are considered hypothetical are not included. Included on all three checklists, however, are species which are reported to have occurred or are possible but for which documentation is poor. A more important measure of the richness of the Guadalupes might be of nesting species, which currently would include about 125 species, historical and current.

The earliest literature available is from the Pope survey which passed along the southern flank of the Guadalupe Mountains during February 28 to March 2, 1854. No specific mention is made on birds from that part of the journey, which is unfortunate, but they did comment on bird life to the west in the Cornudas Mountains and along the Delaware River to the south and east (Bailey 1928).

Florence Merriam Bailey (1928), author of *Birds of New Mexico*, produced some of the earliest literature on birds of the Guadalupes and also one of the finest state bird books, even today, 70 years after publication. She and Vernon Bailey worked in the southern part of the Guadalupes in the late summer of 1901 in the Queen, Dog Canyon, and Salt Flat areas. Her book also contains information on other work done in the mountains up until about 1915 and during some of the initial Carlsbad Cavern surveys in the early 1920s.

Also in 1928, Vernon Bailey published a work entitled *Animal Life of the Carlsbad Cavern*. This was the result of work he had done in conjunction with an initial survey of the Carlsbad Cavern area to see if the area merited national monument status. Although many of the locations mentioned in the text are vague, he did add at least 30 species to the overall Guadalupe Mountains list. Stokely Ligon (1961) authored *New Mexico Birds and Where to Find Them* in which much additional information was provided on the Guadalupes.

On December 24, 1957, the first Christmas count in the area was held at Carlsbad Caverns National Park. These volunteer winter surveys of bird populations within a 7.5 mile radius have served to provide a great deal of information on status and distribution. The first count in Guadalupe Mountains National Park was held in 1964. Over the years, 35 counts have been held at Carlsbad Caverns and 21 at Guadalupe Mountains. One-hundred-sixty-eight species have been recorded at Carlsbad Cavern and over 120 have been found at Guadalupe Mountains National Park. The number of hours in the field has been impressive with over 1,400 party-hours in the field at Carlsbad Caverns. Party-hours reflect the number of hours a party spent in the field (one-to-many people) and not the actual hours of field observations.

Other sources of information have been banding studies which were initiated at Carlsbad Caverns in the 1940s, followed by cave swallow (*Petrochelidon fulva*) work done by Ken Baker in the early 1960s. Additional banding work was done primarily at Rattlesnake Springs, starting in 1979 to the present, and a continuing cave swallow banding and status study at Carlsbad Caverns National Park starting in 1980.

Rattlesnake Springs and the Guadalupe Mountains in general have long been recognized as one of the prime birding spots in the United States (Pettingill 1981, Zimmer 1985). These areas are visited by hundreds if not thousands of birders over the course of a year. Rattlesnake Springs serves as one of the best vagrant traps in the American Southwest. McKittrick and Dog canyons are also visited by many birders with some species there being found easier than anyplace else in the state of Texas. All of this adds up to a growing and valuable accumulation of data on bird distribution—much of it provided by volunteers, birding enthusiasts, photographers, and other visitors.

Because of the general lack of information on bird status from 100 or more years ago, it is difficult to comprehend all the changes that have occurred. Still there are changes that have occurred and have become clearer with time with all the recent information that has been collected. Several of these species are mentioned below in different categories which include "recent changes in status" and "declining species and species of concern."

Recent changes in status

Numerous species have undergone recent population increases. Some of these are recovering populations, some are species that have gradually moved into the area, and others represent recent discoveries of forms that may have been overlooked by earlier researchers.

Turkey vulture (*Cathartes aura*). V. Bailey (1928) reported that the species was "abundant" and that "sometimes two or three hundred were seen together on the roosting grounds." He reported young in the nest before the first of May, and cliffs and canyon walls were reported as nesting and roosting sites. Since Bailey's time the species has abandoned the large roosts in Walnut Canyon and similar spots, although roosts of 50+ birds are known from Last Chance Canyon (Lincoln National Forest) and Big Canyon (Lincoln National Forest). The largest roosts in the area have developed since the mid 1980s at Rattlesnake Springs in the deciduous trees with the maximum count of 400 birds on September 17, 1997 (G. Garber, personal communication). Bailey implied that this species was probably a common nesting species although nests are very rarely reported from anyplace in the area anymore.

White-winged dove (*Zenaida asiatica*). The first report of this species is from Ligon (1961) who reported that it occurred "occasionally on the east side of the Guadalupe Mountains near the Texas line, and in the Pecos Valley about Carlsbad." The species was rare for many years after that until 1970 when 16 were found at Rattlesnake Springs including a nest with well-developed young (Hubbard 1970). The general population in the area gradually grew with the biggest increases and most stable populations being in Carlsbad where large numbers of birds would winter. Birds that occurred during the summer and presumably nested in Big, Walnut, and McKittrick canyons generally left the area during the winter. By the mid 1980s, bird occurred in many of the canyon bottoms and wintered throughout in low numbers. The spread increased and a small population colonized the Queen area (Lincoln National Forest) in 1994 (Snider 1997). This species has spread to most of the Guadalupe Mountains highlands from Robinson Draw to north of Queen and may have even been a minor factor in the decline of band-tailed pigeons.

Inca dove (*Scardafella inca*). The recent arrival was first recorded in the Guadalupes in 1979 (Hubbard and West 1979) at Rattlesnake Springs. Small populations have become established in Carlsbad and other residential areas. Interestingly, this species has yet to be recorded at Guadalupe Mountains National Park and is not known elsewhere in the Guadalupes area except in the area around Rattlesnake Springs and Washington Ranch.

Elf owl (*Micrathene whitneyi*). F. M. Bailey (1928), V. Bailey (1928), and Ligon (1961) did not report this species from the Guadalupe Mountains area. Two to three pairs were reported from the Guadalupe Mountains (probably the lower parts of McKittrick Canyon) by F. R. Gehlbach in 1969 (Oberholser and Kincaid 1974). A small population continues to persist in that area. It was first recorded in Lincoln National Forest in 1997 when a pair was found in upper Dark Canyon on June 16 (Williams 1997) and later in the summer to the north in the lower reaches of Last Chance Canyon (Hibbitts 1997).

Cave swallow *(Petrochelidon fulva*). This species was first found in Slaughter Canyon in 1930 (Johnson 1960) although the initial specimens were misidentified as Cliff swallows (*Petrochelidon pyrrhonota*). It is likely that the species was actually recorded in 1924 when V. Bailey visited the Guadalupes but was again misidentified (West 1995). A "rediscovery" occurred when a colony was found in Goat Cave in Slaughter Canyon, Carlsbad Caverns National Park in June 1952 (Ligon 1961). Since then cave swallows were monitored sporadically until 1980 when a banding program was initiated which continues to this day. Ligon (1961) reported that in 1959 the species was known from four sites at Carlsbad Caverns National Park involving about 200 birds. By 1966 this had expanded to five sites with 213 adults and 319 young (Snider 1966). In 1966 the species first occurred at Carlsbad Caverns and the population there has expanded to approximately 2,000+ birds. The most recent estimate for this species in the Guadalupes (West 1991) recorded the species from 18 caves and 4,720 to 5,220 individuals. Two additional sites were no longer in use. One of the sites was on Bureau of Land Management land, three were in the Lincoln National Forest, and the rest were at Carlsbad Caverns National Park. The species is known to occur at Guadalupe Mountains National Park and probably will eventually be found to nest in the park.

Tufted (black-crested) titmouse (*Baeolophus bicolor*). This species has been reported in recent years in McKittrick Canyon. The closest population occurs in the Davis Mountains, about 100 miles (160 km) to the southeast of McKittrick Canyon (Oberholser and Kincaid 1974). This species either is a recent arrival, a species with a low population base that was overlooked until recently, or no more than a vagrant from the Davis Mountains. This species has never been recorded in New Mexico.

Bronzed cowbird (*Molothrus aeneus*). Apparently the first record for the area was a male at Rattlesnake Springs on May 28, 1983 (Goodman 1983). Since that time the species has occurred sporadically at Rattlesnake Springs and more regularly at feeders in Carlsbad. While it has been reported farther north and east with some regularity, the numbers of this species are still very low and apparently this species has not colonized this northern area well.

Declining species and species of concern

A number of species reported from the Guadalupe Mountains by earlier authors have either declined or may have become extirpated from the mountains. This section includes species that formerly were widespread and now are largely gone.

Zone-tailed hawk (*Buteo albonotatus*). There were few early reports, but F. M. Bailey (1928) reported this species as early at 1901 from Turkey Canyon (Lincoln National Forest). Ligon additionally reported it from Sitting Bull Falls (Lincoln National Forest). Zone-tailed hawk was first reported from Guadalupe Mountains National Park in 1972 (Newman 1974), and the first nest was recorded from Turkey Canyon in 1947 (Ross 1973). Nesting was not recorded again until June 1997 when another nest was discovered in the same canyon (Williams 1997). It probably breeds elsewhere in the mountains, but currently only one nesting pair is known. It is only known as a migrant and vagrant summer visitor at Carlsbad Caverns National Park.

Golden eagle (*Aquila chrysaetos*). F. M. Bailey (1928) reported this species as "very abundant," but now it certainly cannot be regarded as common. A wide variety of factors including legal and illegal persecution, changes in land management strategies, and increased human activity in the area have caused declines in this species. Formerly nested almost annually in Walnut Canyon (Carlsbad Caverns National Park) where five historic nesting sites are located but has not nested since the mid 1980s. Nests elsewhere in Guadalupe Mountains National Park and Lincoln National Forest are low in number. Northern migrants augment winter populations.

Peregrine falcon (*Falco peregrinus*). This species nests in the Guadalupes in very low numbers. Populations were very low in the 1970s and early 1980s but may be slowly recovering. It formerly nested in Lincoln National Forest, but an active nest [in Lincoln National Forest] has not been reported since 1980. They are an uncommon to rare migrant throughout.

Montezuma quail (*Cyrtonyx montezumae*). This species was formerly widespread in the Guadalupes to as low as the entrance of Carlsbad Cavern (V. Bailey 1928). Apparently it became extirpated from the Guadalupes during the mid-1950s (Ross 1973) due to a combination of drought and overgrazing. Ross reported that overgrazing, especially during the growing season, was detrimental to the survival of this species. An intensive wildlife survey of over 2,500 man-hours was conducted on Carlsbad Caverns National Park and Lincoln National Forest lands during the summers of 1971 and 1972 and Montezuma quail were not found. Although secretive and often difficult to locate, it was assumed that the species was extirpated from the Guadalupes. The National Park Service acclimated and released two groups in 1985 totaling about 50 birds, which were originally taken in southern Arizona. Small groups were seen on several occasions, even in the adjacent New Mexico–portion of Dog Canyon, and a pair with young was seen one time. None have been recorded in almost 10 years, although they may still occur.

Yellow-billed cuckoo (*Coccyzum americanus*). Formerly reported as “very common” in the general area (F. M. Bailey 1928) this species is now largely restricted to lowland mesic canyons and riparian areas. It is most common at Rattlesnake Springs (Carlsbad Caverns National Park) with smaller numbers in McKittrick Canyon (Guadalupe Mountains National Park), Big Canyon (Lincoln National Forest), Walnut Canyon (Carlsbad Caverns National Park) and the Sitting Bull Falls–Last Chance Canyon drainages (Lincoln National Forest). Preservation of stands of deciduous trees is a requirement for the continued presence of this species.

Spotted owl (*Strix occidentalis*). This species was probably never common in the Guadalupe Mountains and occurs in only selected areas at this time. It nests in several canyons in the southern part of the Guadalupes and although numbers seem stable, the population is small and the habitat is limited. The species is a permanent resident in the Guadalupe Mountains. The Guadalupes make up the easternmost range for this species, and it is known to occur in all three areas but is not known to nest at Carlsbad Caverns National Park.

Acorn woodpecker (*Melanerpes formicivorus*). Once reported as “abundant” by F. M. Bailey (1928), this species is now very local in the Guadalupes. Currently only very small populations of just a few individuals are known from Dog and McKittrick canyons (Guadalupe Mountains National Park) and Turkey Canyon and possibly upper Dark Canyon (Lincoln National Forest). Birds are rarely seen elsewhere in the mountains. This species requires stands of dead timber; the removal of most of the large ponderosa pines and dead timber has been a factor in their decline.

Scissor-tailed flycatcher (*Tyrannus forficatus*). This species was formerly common at Rattlesnake Springs (Standiford 1965) and probably as a nesting species. Scissor-tailed flycatcher is now rarely found and only in migration. This decline follows the same decline in the species of the Carlsbad area, probably as a result of changes in agriculture as alfalfa gradually replaced cotton. They are common farther east of the Guadalupe Mountains area.

Horned lark (*Eremophila alpestris*). This is a widespread species across much of the Great Plains and western states. It is not rare in the general area and is often recorded in the lowland areas of Carlsbad Caverns and Guadalupe Mountains national parks. V. Bailey (1928) reported that the species breeds “and on top of the Guadalupe Mountains.” Since Bailey made that observation, based on his 1924 field work, West has made the only report of horned larks in the area, i.e., from Lincoln National Forest, in the fall of 1997. This species probably occurs as an uncommon migrant and may even breed on the far northern edge of the forest; there is no known breeding since 1924 and only the one sight record. As juniper and scrub has replaced more open grassland with scattered ponderosa pine, this species has apparently been gradually eliminated from the forest portion of the Guadalupes.

Common raven (*Corvus corax*). The common raven is an adaptable, widespread species found across the northern hemisphere (American Ornithologists’ Union Checklist 1983). It generally persists except under the most vigorous persecution. F. M. Bailey (1928) reported that it “breeds east at least to the Guadalupe Mountains” and that it was fairly common around Carlsbad during the winters of 1915 and 1916. Oberholser and Kincaid (1974) also reported it as rare in the northern trans-Pecos. The status of this species at the turn of the 20th century is not clear although it was certainly present and was probably widespread in at least low numbers and nested in the Guadalupe Mountains. Since that time, records have been very rare and limited primarily to Guadalupe Mountains National Park. During recent forest surveys some birds have been found in the area of Robinson Draw–Hammwell and along the western escarpment of Lincoln National Forest in Otero County. The first recent record for Lincoln National Forest was of a pair feeding four fledged young at Robinson Draw on July 9, 1994 (Snider 1998). Since that time there have been half-a-dozen records in the areas, usually of pairs.

Bell’s vireo (*Vireo bellii*). Virtually the entire population of this species in southeast New Mexico is located in the Rattlesnake Springs area. While heavily impacted by brown-headed cowbirds (*Molothrus ater*), the population seems stable. The existence of this species in southeastern New Mexico is contingent on good habitat management at Rattlesnake Springs. Alteration of the limited native riparian habitat could eliminate Bell’s vireo as a breeding species.

Varied bunting (*Passerina versicolor*). Varied buntings are considered rare to uncommon in the two parks and have not yet been found on Lincoln National Forest land. In the 1960s and early 1970s they were found with some regularity at Carlsbad Caverns National Park but have since become somewhat rare and difficult to find. The Guadalupes are at the northeastern extremity of range for this species. It is possible that it is overlooked and not all canyons have been checked for breeding territories. Precipitation may be an important factor on the presence of birds in canyons in the area.

Orchard oriole (*Icterus spurius*). This species is often common at Rattlesnake Springs and also occurs in surrounding areas in low numbers. The presence of native riparian vegetation, particularly large deciduous trees, is necessary for this species to nest in the area. Without such trees, this species would decline and eventually disappear. The almost total destruction of native riparian vegetation along surrounding rivers has made Rattlesnake Springs even more important for a growing number of species.

Hooded oriole (*Icterus cucullatus*). This species may be one of the rarest of breeding species in the Guadalupes area. Occasionally a pair or two are found at Rattlesnake Springs, but it is unreported some years. As with the orchard oriole, maintenance of riparian woodland is necessary if this species is to persist in the area.

Birds and all other species must be taken into account when devising management plans. What effect will new trails and campsites, fuelwood areas, grazing and extended waterlines, prescribed fire or lack of prescribed fire have on these populations? Some current populations are restricted and declining because of natural forces; others have been lost or will be lost in the future because of land policy and management decisions. There can be little doubt that human activities have accelerated many of these changes and made others possible. If there is a desire to maintain a native balance in the Guadalupe Mountains, avifauna that occupies this sky island will have to be considered.

Composite species list for the Guadalupe Mountains of New Mexico and Texas

Table 1 is a composite of three checklists for the three major political entities in the Guadalupes; Carlsbad Caverns National Park, Guadalupe Mountains National Park, and Lincoln National Forest. It has been difficult to illustrate the status of each species in each area without at least a moderate amount of confusion. Every attempt has been made to reflect the true status of each species and with only a few exceptions, the checklists have been followed without deviation (Carlsbad Caverns Guadalupe Mountains Association 1997).

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Table 1. Each species is followed by a status designation and then seasonal status. If it occurs in only one season it is noted in that manner. Species known to occur as both spring and fall migrants are recorded as migrant. Some species are known to occur in only one migration season. Some species (mostly breeding species) occur spring through fall (sp-fa).

	Carlsbad Caverns	Guadalupe Mountains	Lincoln National Forest
PODICIPEDIDAE			
pied-billed grebe	r-uc, fa-sp	r, fa	acc, fa
eared grebe	r, m	o, fa	
western grebe	acc, w		
PELECANIDAE			
American white pelican	acc, sp	acc, m	acc, fa
brown pelican		acc, su	
PHALACROCORACIDAE			
double-crested cormorant	acc, fa		
ARDEIDAE			
American bittern	r, m		
least bittern	acc, sp		
great blue heron	uc-o, pr	r-o, pr	
great egret	r, sp	o, m	
snowy egret	uc, m	o, sp	
tricolored heron	acc, su	acc, su	
cattle egret	o, m	o, sp-fa	
green heron	fc-r, sp-fa	o, sp	acc, fa
black-crowned night-heron	r-o, sp-fa	acc, su	acc, su
THRESKIORNITHIDAE: ibises and spoonbills			
white ibis	acc, sp	acc, su	
white-faced ibis	uc-m	acc, su	
CATHARTIDAE: American vultures			
black vulture		acc, su	
turkey vulture	c, sp-fa	c, sp-fa	c, sp-fa
ANATIDAE: swans, geese, and ducks			
black-bellied whistling-duck	acc, sp		acc, fa
snow goose	r, f-sp	o, fa	
Canada goose	r, wi	o, sp	
tundra swan	acc, sp		
wood duck	r-o, m	o, fa-sp	
gadwall	c-uc, fa-sp	uc, fa-sp	r, fa
american wigeon	uc, fa-sp	uc, fa-sp	
mallard	fc-r, pr	r, fa-w	r, w
blue-winged teal	fc-r, fa-sp	occ, sp-fa	uc, fa
cinnamon teal	fc-r, fa-sp	o, sp-fa	r, fa
northern shoveler	c-fc, fa-sp	o, sp-fa	
northern pintail	c-uc, fa-sp	o, fa-w	
green-winged teal	c, fa-sp	r, sp-fa	r, fa-w
canvasback	r-o, fa-sp	o, sp-fa	
redhead	uc-r, fa-sp	o, sp-fa	
ring-necked duck	fc-uc, fa-sp	uc, fa-sp	acc, sp, w
lesser scaup	r-c, pr	o-w	
bufflehead	uc-r, fa-sp	o, sp	
common goldeneye	uc-r, fa-sp		
hooded merganser	acc, m		
common merganser	r, w	o, fa-w	
ruddy duck	uc-r, fa-sp	o, fa	acc, w
ACCIPITRIDAE: kites, eagles, hawks and allies			
osprey	r, m	o, sp-su	
white-tailed kite	acc, w	acc, w	
Mississippi kite	r-acc, m	acc, p-su	
bald eagle	acc, w	o-acc, pr	r, fa-sp
northern harrier	c-uc, pr	fc-r, pr	
sharp-shinned hawk	fc-uc, fa-sp	fc-r, pr	uc, fa-sp
Cooper's hawk	uc, pr	fc-uc, pr	uc, pr
northern goshawk	o, f-w	o, m	acc, fa
common black-hawk	acc, sp	o, m	
Harris' hawk	r, pr	o, w-sp	
red-shouldered hawk	acc, sp		
broad-winged hawk	acc, m	acc, sp	

Status

acc- accidental
o-occasional
r- rare
uc-uncommon
fc- fairly common
c- common
extir-extirpated

Season

sp-spring
su-summer
fa- fall
w- winter
m-migrant (spring and fall)
pr-permanent resident

	Carlsbad Caverns	Guadalupe Mountains	Lincoln National Forest
ferruginous hawk	fc-r, pr	r-acc, pr	r, w
rough-legged hawk	uc-r, w-sp	o, fa-w	
golden eagle	fc-uc, pr	fc, pr	uc, pr
FALCONIDAE: caracaras and falcons			
crested caracara		acc, fa	
American kestrel	c-uc, pr	c-uc, pr	uc, pr
merlin	acc-w	o,fa	acc,fa
prairie falcon	fc-r, pr	uc-r, pr	
peregrine falcon	r, m	r, pr	r, sp-fa
PHASIANIDAE: pheasants, grouse, and turkeys			
ring-necked pheasant	r, pr	o, fa-sp	
lesser prairie chicken	acc, fa		
wild turkey	fc, pr	uc, pr	uc, pr
ODONTOPHORIDAE: quail			
Montezuma quail	extir	r, pr	extir
northern bobwhite	r, pr	o, pr	
scaled quail	c, pr	c, pr	r, pr
Gambel's quail		acc, sp	
RALLIDAE: rails, gallinules, and coots			
Virginia rail	uc-r, fa-sp	acc, sp	
sora	r, fa-w	acc, fa	
common moorhen	r-acc, w-sp		
American coot	c-r, pr	r, fa-sp	
GRUIDAE: cranes			
Sandhill crane	fc-uc, fa-sp	uc-o, fa-sp	r, sp
whooping crane		acc, m	
CHARADRIIDAE: plovers			
killdeer	c, pr	uc-r, pr	r, fa-sp
RECURVIROSTRIDAE: avocets and stilts			
black-necked stilt	r, m		
American avocet	r, m	acc, fa	acc, sp-su
SCOLOPACIDAE: sandpipers, phalaropes, and allies			
greater yellowlegs	uc, m		acc, fa
lesser yellowlegs	uc, m	acc, fa	acc, fa
solitary sandpiper	uc-r, m	o,fa	acc,fa
willet	o, sp		
spotted sandpiper	uc, m	o, sp-su	uc, fa
upland sandpiper	fc, fa		
long-billed curlew	r, m	acc, fa	
sanderling		acc, fa	
western sandpiper	fc, m	o, fa	
least sandpiper	fc-o, fa-sp	acc, fa	
Baird's sandpiper	r, m	acc, fa	
stilt sandpiper		o, fa	
long-billed dowitcher	uc, m		
common snipe	c-acc, pr	r, fa-w	
American woodcock	acc, w		
Wilson's phalarope	fc, m		
red-necked phalarope	r, fa		
LARIDAE: skuas, gulls, terns, and skimmer			
Franklin's gull	acc, sp		
ring-billed gull	o, w	r, fa-w	
herring gull		o, w	
black tern	uc, m		
COLUMBIDAE: pigeons and doves			
rock dove	o, pr	o, sp-fa	
band-tailed pigeon	r, pr	r, sp-fa	r, sp-fa
white-winged dove	c-fc, pr	c, pr	fc, sp-fa
mourning dove	c-fc, pr	c-uc, pr	fc, pr
inca dove	uc-r, pr		

Status

acc- accidental
o-occasional
r- rare
uc-uncommon
fc- fairly common
c- common
extir-extirpated

Season

sp-spring
su-summer
fa- fall
w- winter
m-migrant (spring and fall)
pr-permanent resident

	Carlsbad Caverns	Guadalupe Mountains	Lincoln National Forest
yellow-billed cuckoo	fc-r, sp-fa	r, su-fa	uc, sp-su
greater roadrunner	fc, pr	fc, pr	r, r
groove-billed ani	acc, fa		
TYTONIDAE: barn owls			
barn owl	r, pr	o, sp-su	
STRIGIDAE: owls			
flammulated owl	o, su-fa	uc, sp-fa	acc, su
western screech owl	r, pr	uc, pr	uc, su
great horned owl	fc, pr	c, pr	fc, pr
northern pygmy-owl		r, sp-fa	acc, m
elf owl		acc, sp-su	r, su
burrowing owl	o, pr	r, pr	
spotted owl	o, w-sp	r, pr	uc, pr
long-eared owl	acc, w	o, w-sp	
short-eared owl	r-acc, w-sp	acc, fa	
northern saw-whet owl		o, sp-su	acc, su
CAPRIMULGIDAE: nighthawks and nightjars			
lesser nighthawk	c-acc, pr	r, sp-fa	
common nighthawk	c, p-fa	c-fc, sp-fa	c, su
common poorwill	c-r,pr	c-uc, sp-fa	c, p-fa
whip-poor-will	r, sp-su	uc-r, sp-fa	r, su
APODIDAE: swifts			
chimney swift	acc, fa		
white-throated swift	uc-r, pr	c-acc, pr	c, sp-fa
TROCHILIDAE: hummingbirds			
broad-billed hummingbird	acc, sp		
white-eared hummingbird		acc, su	
blue-throated hummingbird	o, su	r, sp-fa	
magnificent hummingbird	acc, su	r, sp-fa	acc, su
ruby-throated hummingbird		acc,su	
black-chinned hummingbird	c, sp-fa	c, sp-fa	uc, sp-su
Anna's hummingbird	acc, sp		
calliope hummingbird	acc, fa	r, su-fa	
broad-tailed hummingbird	fc, m	c, sp-fa	fc, sp-fa
Rufous hummingbird	c-fc, su-fa	fc, su-fa	uc, su-fa
TROGONIDAE: trogons			
elegant trogon			acc,su
ALCEDINIDAE: kingfishers			
belted kingfisher	fc, fa-sp	uc-r, sp-fa	acc, sp
PICIDAE: woodpeckers			
Lewis' woodpecker		o-acc, fa-sp	acc, w
red-headed woodpecker	acc, sp	acc, fa-w	
acorn woodpecker	uc, pr	c, pr	uc, pr
red-bellied woodpecker	o, fa-w		
yellow-bellied sapsucker	o, fa-w	r, w	
red-naped sapsucker	uc, fa-sp	fc, fa-w	r, fa-sp
Williamson's sapsucker	acc, fa-w	r-o, fa-sp	
ladder-backed woodpecker	c, pr	c, pr	c, pr
downy woodpecker	r, fa-sp	r, fa-sp	
hairy woodpecker	uc-r, a-sp	fc, pr	uc, pr
northern flicker	c-fc, pr	c-uc, pr	uc, pr
TYRANNIDAE: tyrant flycatchers, becards			
olive-sided flycatcher	uc-r, m	uc, sp-fa	uc, fa
western wood-pewee	c-r, sp-fa	c, sp-fa	c, sp-fa
eastern wood-pewee	acc, fa		
willow flycatcher	uc, m	acc, su	r, m
least flycatcher	acc, sp-su		
hammond's flycatcher	uc, m	r, fa-sp	
dusky flycatcher	fc, m	fc, r-sp-fa	
gray flycatcher	o, m	acc, sp-su	uc, sp-su
cordilleran flycatcher	fc, m	c, sp-fa	uc, sp-su

Status	Season
acc- accidental	sp-spring
o-occasional	su-summer
r- rare	fa- fall
uc-uncommon	w- winter
fc- fairly common	m-migrant (spring and fall)
c- common	pr-permanent resident
extir-extirpated	

	Carlsbad Caverns	Guadalupe Mountains	Lincoln National Forest
vermilion flycatcher	c-r ,pr	o, sp-fa	
ash-throated flycatcher	c, sp-fa	c, sp-fa	c, sp-fa
great crested flycatcher	o, m		
brown-crested flycatcher		acc, sp-su	
great kiskadee	acc, sp-su		
piratic flycatcher	acc, fa		
Cassin's kingbird	c-uc, sp-fa	fc, sp-su	c, sp-fa
western kingbird	c, sp-fa	uc-sp-fa	r, m
eastern kingbird	acc, sp-fa		
scissor-tailed flycatcher	uc-r, sp-fa	acc, su	
LANIIDAE: shrikes			
northern shrike		acc, w	
loggerhead shrike	c-fc, pr	fc, pr	r, fa
VIREONIDAE: vireos			
white-eyed vireo	acc, sp	acc, su	
Bell's vireo	c-uc, sp-fa	r, sp-su	
gray vireo	fc, sp-fa	fc-uc, sp-fa	uc, sp-su
blue-headed vireo	acc, fa		
plumbeous vireo	fc-uc, sp-fa	c-o, pr	c, sp-su
yellow-throated vireo	acc, fa	acc, su	
Hutton's vireo		r-sp-fa	acc, w
warbling vireo	fc-uc, sp-fa	c-uc, su-fa	r, m
Philadelphia vireo	acc, fa	acc,sp	
red-eyed vireo	o, m	acc, sp-su	
yellow-green vireo	acc,su		
CORVIDAE: jays, magpies, crows			
Steller's jay	r, fa-sp	fc, pr	uc, pr
blue jay	acc, m	acc, su	
western scrub-jay	fc-r, pr	c-uc, pr	c, pr
pinyon jay	r, fa-wi	uc-r, pr	c-r, pr
Clark's nutcracker	acc, su & wi	acc, fa-sp	
black-billed magpie	acc, sp		acc, fa
American crow	acc, w	acc, w	
Chihuahuan raven	r, pr	r, fa-sp	acc, sp
common raven		r, fa-sp	r, pr
ALAUDIDAE: larks			
horned lark	pr, c	uc, pr	acc, fa
HIRUNDINIDAE: swallows			
purple martin	acc, su-fa	acc, su	acc, su
tree swallow	uc, m	r, m	
violet-green swallow	fc-uc, sp-fa	c, sp-fa	fc, sp-su
northern rough-winged swallow	fc, m	uc, m	
bank swallow	r, sp		
barn swallow	c, sp-fa	uc, sp-fa	uc, sp-su
cliff swallow	fc, sp-fa	c, sp-fa	c, sp-fa
cave swallow	c, sp-fa	o, su	fc, sp-fa
PARIDAE: titmice			
mountain chickadee	uc-r, pr	c, pr	fc, pr
juniper titmouse	uc-r, pr	uc, pr	uc, pr
tufted titmouse		o, sp-su	
REMIZIDAE: penduline tits, verdins			
verdin	uc, pr	uc, pr	
AEGITHALIDAE: long-tailed tits, bushtits			
bushtit	fc-uc, pr	c, pr	fc, pr
SITTIDAE: nuthatches			
red-breasted nuthatch	o, fa-wi	uc-o, pr	uc, fa-sp
white-breasted nuthatch	uc, fa-sp	c, pr	fc, pr
pygmy nuthatch	r, pr	fc, pr	uc, pr
CERTHIIDAE: creepers			
brown creeper	r, fa-w	uc, pr	
TROGLODYTIDAE: wrens			

Status

acc- accidental
o-occasional
r- rare
uc-uncommon
fc- fairly common
c- common
extir-extirpated

Season

sp-spring
su-summer
fa- fall
w- winter
m-migrant (spring and fall)
pr-permanent resident

	Carlsbad Caverns	Guadalupe Mountains	Lincoln National Forest
carolina wren	o, fa		
Bewick's wren	c-fc, pr	c, pr	c, sp-fa
house wren	c-o, fa-sp	uc, pr	r,m
winter wren	o, w-sp	occ, fa-sp	
sedge wren	acc, w		
marsh wren	fc-fa-sp	acc, m	acc, fa
CINCLIDAE: dippers			
American dipper	acc, w	occ, fa-sp	acc, fa
REGULIDAE: kinglets			
golden-crowned kinglet	uc-o, w-sp	uc, fa-sp	
ruby-crowned kinglet	c-fc, fa-sp	c-r, pr	uc, fa-sp
SYLVIIDAE: Old World warblers			
blue-gray gnatcatcher	uc-o, pr	c-fc, pr	fc, sp-su
black-tailed gnatcatcher	o, pr	r, w-su	r, su
TURDIDAE: thrushes			
eastern bluebird	uc, pr	r, fa-w	
western bluebird	fr-r, pr	c-uc, pr	fc, pr
mountain bluebird	uc-r, fa-sp	c-o, pr	uc, fa-sp
Townsend's solitaire	fc, fa-sp	c-o, pr	fc, fa-sp
Swainson's thrush	uc, m	r, m	
hermit thrush	fc, fa-sp	c, pr	uc, m
wood thrush		acc, sp	
American robin	c-fc, fa-sp	c-o, pr	fc, pr
varied thrush	acc, fa	acc, m	
MIMIDAE: mockingbirds, thrashers			
gray catbird	occ-fa-sp	acc, w-sp	
northern mockingbird	c-fc, pr	c-uc, pr	c, sp-fa
sage thrasher	c-uc, fa-sp	fc-uc, fa-w	
brown thrasher	fc, fa-sp	r, fa-sp	
long-billed thrasher	acc-fa-sp		
curve-billed thrasher	fc-pr	fc-uc, pr	pr, uc
Crissal thrasher	uc, pr	uc, pr	r, su-fa
STURNIDAE: starlings			
European starling	fc-uc, pr	o, fa-sp	
MOTACILLIDAE: pipits			
American pipit	fc-uc, fa-wi	r, fa-sp	
Sprague's pipit	acc, fa		
BOMBYCILLIDAE: waxwings			
Bohemian waxwing		acc, fa-w	
cedar waxwing	uc, fa-sp	fc, fa-sp	
PTILOGONATIDAE: silky flycatchers			
phainopepla	o, pr	fc-r, pr	uc, sp-su
PARULIDAE: wood warblers			
blue-winged warbler	acc, fa		
golden-winged warbler	acc, sp		
Tennessee warbler	o, m		
orange-crowned warbler	fc-o, fa-sp	fc, sp-fa	
Nashville warbler	uc-r, m	o, m	
Virginia's warbler	fc, m	fc-uc, sp-fa	r, su
Lucy's warbler	acc, sp-su		
northern parula	acc, m	acc, su-fa	
yellow warbler	fc, m	uc, m	uc,m
chestnut-sided warbler	acc, sp	acc, su	
magnolia warbler	acc, sp		
Cape May warbler	acc, sp		
black-throated blue warbler	acc, fa	acc, m	
yellow-rumped warbler	c-uc, fa-sp	c-r, pr	c, m
black-throated gray warbler	fc-uc, m	uc-r, sp-fa	uc, sp-su
Townsend's warbler	r, fa	c, m	uc, fa
hermit warbler	acc, m		
black-throated green warbler	r, fa	acc, su	

Status	Season
acc- accidental	sp - spring
o-occasional	su - summer
r- rare	fa- fall
uc-uncommon	w- winter
fc- fairly common	m-migrant (spring and fall)
c- common	pr-permanent resident
extir-extirpated	

	Carlsbad Caverns	Guadalupe Mountains	Lincoln National Forest
pine warbler	acc, w	acc, fa	
bay-breasted warbler	acc, m		
blackpoll warbler	acc, m		
Cerulean warbler	acc, sp		
black-and-white warbler	r-o, sp-fa	acc, sp	
American redstart	r-o, sp-fa	r, m	
prothonotary warbler	acc, sp		
worm-eating warbler	acc, m	acc, su	
Swainson’s warbler	acc, fa		
ovenbird	acc, sp	acc, sp-fa	
northern waterthrush	uc, m	acc, su-fa	
Louisiana waterthrush	acc, fa		
Kentucky warbler	acc, sp	acc, sp	
Connecticut warbler	acc, fa		
MacGillivray’s warbler	fc, m	fc-o, sp-fa	fc, fa
common yellowthroat	fc-uc, sp-fa	r, sp	
hooded warbler	acc, sp	acc, sp	
Wilson’s warbler	c-acc, fa-sp	c-o, sp-fa	c, m
Canada warbler	acc, sp		
painted redstart	acc, sp	c-acc, sp-fa	
yellow-breasted chat	c-uc, sp-fa		r, su
THRAUPIDAE: tanagers			
hepatic tanager	uc-r, sp-fa	fc, sp-fa	fc, sp-su
summer tanager	c, sp-fa	r, sp-su	uc, sp-su
scarlet tanager	acc, fa	acc, su	
western tanager	fc, m	c, sp-fa	fc, sp-su
EMBERIZIDAE: sparrows			
green-tailed towhee	fc-uc, fa-sp	uc, pr	uc, fa
eastern towhee	acc, w		
spotted towhee	c-fc, fa-w	c-uc, pr	fc, sp-fa
canyon towhee	c, pr	c, pr	c, pr
Cassin’s sparrow	c-acc, pr	uc-r, pr	r, su
Rufous-crowned sparrow	c, pr	c, pr	fc, pr
American tree sparrow	acc, w-sp	o, w	
chipping sparrow	c-fc, fa-sp	c, pr	c, pr
clay-colored sparrow	uc, m	r, sp-su	
Brewer’s sparrow	c-uc, fa-sp	fc, fa-sp	fc, fa
field sparrow	r, fa-sp	r, w	
black-chinned sparrow	fc-uc, pr	c-uc, pr	fc, sp-fa
vesper sparrow	fc, fa-sp	uc, m	fc, fa
lark sparrow	c-o, pr	fc-r, pr	fc, sp-su
black-throated sparrow	c, pr	c, pr	r, sp-fa
sage sparrow	uc, fa-w	uc, w	
lark bunting	c-fc, fa-sp	uc-r, sp-fa	r, fa
savannah sparrow	fc-r, fa-sp	occ, fa-w	uc, fa
Baird’s sparrow	acc, sp	acc, fa	acc, fa
grasshopper sparrow	o, fa-sp	acc, sp	
LeConte’s sparrow	acc, fa		
fox sparrow	uc, fa-sp	r-acc, w-sp	
song sparrow	c, fa-sp	r, fa-sp	r, w
Lincoln’s sparrow	c-fc, fa-sp	uc, fa-sp	
swamp sparrow	c-fc, fa-sp	acc, fa-w	
white-throated sparrow	fc-uc, fa-sp	r, w-sp	r, w
Harris’ sparrow	o, w-sp		
white-crowned sparrow	fc-uc, fa-sp	c-fc, fa-sp	uc, fa-sp
golden-crowned sparrow	acc, m		
dark-eyed junco	c-uc, fa-sp	c, fa-sp	fc, pr
yellow-eyed junco		acc, m	
McCown’s longspur	acc, w	acc, w-sp	
chestnut-collared longspur	r, w	acc, sp	
CARDINALIDAE: cardinals and grosbeaks			
northern cardinal	fc, pr	occ, su & wi	

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	Carlsbad Caverns	Guadalupe Mountains	Lincoln National Forest
black-headed grosbeak	fc, mi	c-fc, sp-fa	fc, sp-su
blue grosbeak	c, sp-fa	c-fc, sp-f	fc, sp-su
lazuli bunting	r, m	uc, m	
indigo bunting	uc-occ, sp-fa	uc, mi	acc, su
varied bunting	r, sp-su	acc, su	
painted bunting	c-fc, sp-fa	acc, fa	acc, fa
dickcissel	r-o, sp-fa		acc, sp
ICTERIDAE: blackbirds and orioles			
bobolink	o, fa		
red-winged blackbird	c-fc, pr	r, sp-fa	r, sp-su
eastern meadowlark	c-uc, pr	c, pr	uc, su
western meadowlark	c, pr	c-r, pr	
yellow-headed blackbird	uc-oc, pr	r-o, fa-sp	r, su
rusty blackbird	o, fa-w		
Brewer's blackbird	c, fa-sp	uc, m	uc, fa
common grackle	o, sp	o, sp-su	
great-tailed grackle	r, pr	o, pr	r, sp
bronzed cowbird	r, sp-su	acc, su	
brown-headed cowbird	c, pr	c, sp-fa	c, sp-fa
orchard oriole	c-fc, sp-su		
hooded oriole	r, sp-su	acc, sp-su	
Baltimore oriole	r, m		
Bullock's oriole	c, sp-fa	r, sp-su	r, sp-su
Scott's oriole	c, sp-fa	c, sp-su	fc, sp-su
FRINGILLIDAE: finches			
purple finch	acc, w	acc, sp-su	
Cassin's finch	uc, w	uc, fa-sp	r, sp
house finch	c, pr	c, pr	c-uc, pr
red crossbill	acc, su	uc, pr	uc, w-su
pine siskin	c-fc, fa-sp	uc, pr	uc-r, pr
lesser goldfinch	c-fc, pr	c, pr	uc, sp-su
American goldfinch	fc-o, pr	uc-o, pr	uc, fa
evening grosbeak	o-acc, w-sp	r-o, pr	
PASSERIDAE: weaver finches			
house sparrow	c, pr	c, pr	r, sp-su

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Chapter 10

The Texas GAP Project: Status and Potential

NICK C. PARKER, Ph. D., has been a professor and unit leader for the U.S. Geological Survey, Texas Cooperative Fish and Wildlife Research Unit for the past 27 years. He has completed projects associated with Guadalupe Mountains National Park on vegetation cover, vertebrate distribution, and land use. He is currently involved with the Texas GAP Analysis Program, Rio Grande GAP Analysis Program, and the Texas Natural Resource Database. Other authors: CARLOS GONZALEZ-REBELES, T. SCOTT SCHRADER, ANDREA E. ERNST, YONGLUN LAN, KELLY E. ALLEN, ERIC HOLT, and SHERI HASKELL.

It's a pleasure for me to be here. I have certainly enjoyed the presentations I have heard up until this point, and I am sure that the rest of the presentations, perhaps with this one exception, will be very good. What I would like to do is give you a broad overview on what the gap analysis program (GAP) is, how it ties in with the Museum at Texas Tech University, and how this effort is unique among GAP projects. I would like to show you the reason we need a cooperative effort, the importance of the Guadalupe Mountains and how all of these pieces are fitting together in the big picture. To give you that view, I would like to start with the slides, with the big picture approach, and let's see if we can bring it back to what really applies right here.

First of all, the title has my name on it. However, I am just representing all these students sitting in the front row, many others back in the lab, and others who are working on this cooperative project. Whatever I present, these students and staff have produced it; however, when the student made the title, he put my name on it.

We have the opportunity to step back and look at the world from afar, from space. We see it as a very different place than our ancestors did. Today, we can look at the entire United States in one view. We can see detail with satellite imagery that we have never before been able to see. We can zoom in and look at not only the detail of Texas, as this soil map indicates, but with Landsat and satellite imagery, we can look at details that we have not been able to envision previously. From the Landsat scene containing the Guadalupe Mountains, we can now develop maps depicting vegetation and land use. We can use the information that we gather remotely to help us understand the world around us and to help us make decisions necessary to preserve and maintain the unique ecosystem of the Guadalupe Mountains. To do that, I would like for us to see how the Guadalupe Mountains fit into the big picture. We are the first civilization that has ever had this power. Every civilization before us has collapsed, arguably, because they exhausted their local natural resources and changed the world in which they lived to the extent that it could no longer support their societies. This has been true through time. If we look at the Mediterranean hills and valleys of today, they are quite different than those seen by earlier societies. At one time all of those hills were forested. Consider the Nile Valley—it was a forest at one time. Ancient people exploited the resources but did not have the management tools that we have to work with today. We are all familiar with the large-scale problems that we have in the world today. We recognize the problems of water shortage, soil erosion, pollutants, an expanding human population, and the loss of natural habitat. However, we typically see these problems as somewhere else; it's difficult to see them in our own backyard. Yet, these problems influence what we do. If we look at the

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human population, the world is growing at such a rate that we don't really have a problem with resources, habitat, and animals; we have a problem with people. It is difficult for us to focus on the human population problem so we therefore focus on these other problems of resources, habitat, and animals. We try to manage the habitat that we have left.

Let's consider the way we are changing the environment around us. Just in the last few years up until 1950 we were annually using about three million tons of nitrogen fertilizer. By 1990 fertilizer use was up to 50 million tons and increasing. The yield of corn per hectare from 1866 to 1993 has increased rapidly and even exponentially in recent years. This increased use of fertilizers, production of corn and other food and fiber products is impacting the world in which we live. To the southwest of the Guadalupe Mountains, west of El Paso, there is a concentration of dairies with thousands of cows and each dairy cow requires about 22 gallons (83 L) of water per day. Throughout the Texas panhandle we have cattle feedlots and large swine production facilities. Each steer requires about 8 gallons (30 L) of water per day and sows require about 4 gallons (15 L) each. All of these industries are needed to support our society. Modern industries tax our society and our natural resources; however, for our society to exist we must have these industries. Our society requires energy and most energy production involves carbon emissions. In the 100 years from 1860 to 1960 carbon emissions into the atmosphere were about a billion tons per year. From 1960 to 1990, 2.7 billion tons of carbon were released annually into the atmosphere. Not only does our modern society affect the atmosphere, it also impacts the world's oceans. For example, an aerial photograph of a coastal bay in southeast Alaska showed 29 boats with nets capturing salmon. There are captains of these vessels that tell you when they started fishing with their fathers they used a stone and string to determine the depth of the water. Today with the equipment these fishermen have on board, they can tell you with 95% confidence that they will take 98% of the fish in a school they find, and they can find them all. Fishermen today can capture essentially all of the fish. Today, man and modern society has the capability to manipulate the world's environment. When one stands on the shore at Galveston, Corpus Christi, or any other coastal city and looks out to sea, the sea appears so large we easily believe that man could never impact it. Now we find that 29% of the fish are over-exploited, 45% fully-exploited, 22% moderately-exploited, and only 4% are under-exploited. As we critically examine our world it's easy to see that modern society has changed the natural environment. We are very quickly changing the world we love into something that may no longer meet our needs or be satisfactory to us or our children. We have to find ways that we can address these issues.

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In this part of the country, we are very concerned and very aware of the precious value of water, the quality of the water, and the price we are paying for it. In west Texas we have about 3,500 cubic meters of water per person per year. Israel has about 480 cubic meters and Saudi Arabia about 300 cubic meters of water per person, and life goes on. So no matter how difficult or how hard it is to acquire water, we can and will adjust to life with a limited supply of water. A degraded quality of life is our future unless we take measures today to preserve our natural resources and protect our environment. What I wish to present to you is a planning tool to help us maintain a quality environment and biodiversity. Biodiversity—the high diversity of life forms, a species-rich biological system—is something we must maintain. Tools such as the National Gap Analysis Program can help us maintain the biological diversity of the world by providing the information needed for natural resource managers, developers, landowners, and all factions of society to make better decisions.

Scientists today have described about 1.4 million species, but it is estimated that there are 25 to 50 million species living today, and we are annually losing to extinction an estimated 30 to 300,000 species. We don't really know how many species exist and we will not know until we survey and inventory our biological world. That we need to keep conducting inventories, is a difficult thing for us to sell to the public. In a 21 square meter area of the North Atlantic, scientists found 898 species, 100 families, and 12 phyla. Of the 898 species, 460 (51%) were not described, and 200 repetitive samples continued to yield new species at the same rate. We have heard a great deal about the rain forest and the large number of species living there. This is the world on which we live and we don't even know what treasures of life it contains. Therefore, programs like gap analysis and geographical information systems (GIS) provide the tools necessary to organize data and help us understand the complexity of our world. The GIS layers and associated databases can help us make wiser decisions. The tools available to us today include computer software, hardware, relational databases, image analysis, electronic exchange of museum collections, and GIS GAP analysis. All of these tools are giving us the power to make decisions based on science. Our predecessors and earlier civilizations did not have the opportunity to use the powerful analytical tools available to us today.

There are 47 Landsat scenes covering the state of Texas. These scenes have been used to map vegetation and land use based on interpretation of the satellite imagery. We have the potential to meld different interests and the expertise of groups such as the mammalogists of the museum, staff of Texas Parks and Wildlife Department, and the Texas Health Department. Professionals from these organizations are in the field daily. They are collecting data. They are answering questions for their agency. When they're finished, field biologists usually produce a narrowly focused report to answer immediate questions and then it is buried in some agency file. We now have the opportunity to pull all these data together, to build relational databases so that a large body of information about a species, a place, or an ecoregion can be linked together and used to make better decisions. As one example, the museum collection of mammals includes species of great concern to federal and state agencies. The swift fox, or kit fox, is a species of concern and has been discussed as a species that might be listed as threatened or endangered by the U.S. Fish and Wildlife Service. When we examine the biological data, what do we have? We find that the mammal collection of the Museum of Texas Tech University (one of the largest collections of mammals in the Southwest) contains only 10 specimens of swift foxes. We have one specimen from four counties and two specimens from three counties. How can we make sound biological decisions based on such sparse data? We need data in a database that provides enough information to support valid and wise decisions. Many people look at museum collections as history. They often naively argue that we don't need to add to museum collections because they view the museum collections as static history. Contrarily, museum collections provide a dynamic reflection of our world and can be used by resource managers to make better decisions.

Many people look at museum collections as history. They often naively argue that we don't need to add to museum collections because they view the museum collections as static history.

As another example, Dr. Robert Baker and fellow scientists in the museum have been able to work with the Texas Department of Health to examine the incidence of rabies in bats. The number of rabid bats collected annually in Texas has been pretty stable. However, when the spatial distribution of rabid bats is examined over time we find that one year the bats with rabies were in the middle of the state and the next year they were in the eastern part of the state. The third year rabid bats were found primarily along the Gulf Coast. People who understand bat biology, bat behavior, where bats spend winters, and where they feed have only a partial understanding of bat ecology. We must bring in people from the agricultural community to know what has happened to the habitat. For example we know that in south Texas a large part of the cotton producing area was sprayed with pesticides to control cotton boll weevils. When we poison boll weevils, do we poison non-target organisms on which bats feed? Do those bats now shift to a different place to feed? These are very complex ques-

Quality decisions begin in the field when data are collected with specimens, properly prepared, and moved back into museums.

tions and cannot be answered without valid data. It is these broad- scale questions that we are now trying to address. The value of data based on tissues and in museum collections is far greater than that of data produced without voucher specimens. Voucher specimens provide positive proof that the species collected was properly identified by a curator. When we have voucher specimens and tissue samples from which DNA can be analyzed, we can provide positive identification of species, gender, and a myriad of other information encoded in the DNA. Museums can provide the irrefutable data necessary for society to make decisions that are really solid and valuable.

Good decisions are based on very good field data. We can prepare no models, no maps, and no information that is any better than the data upon which those products are based. Quality decisions begin in the field when data are collected with specimens, properly prepared, and moved back into the museums. Once in the museum, specimens are properly identified using advanced techniques as required. The Museum of Texas Tech University has about 75,000 mammals, 15,000 reptiles-amphibians, 10,000 fishes, and 4,500 birds as curatorial specimens, plus about 70,000+ cryogenically preserved tissue samples. These voucher specimens, tissues, and their allied databases allow Dr. Baker and other scientists to answer questions about the distribution of hantavirus and know that it is found in a specific location, in a specific species. When we link these data to a GIS and GAP, we can begin to ask questions about how rainfall, crops, and El Niño change the rodent population in which hantavirus is found. Would full knowledge of hantavirus change the way we manage natural resources? Would this knowledge help us reduce health risks to people? It is important to know that when tourists are out backpacking and exploring remote trails, they are aware of areas with a high susceptibility for exposure to hantavirus. Field collections of small mammals and screening surveys for viruses provide the kinds of data needed to make decisions affecting natural resources and human health.

In the museum at Texas Tech bar code tags are used to mark and identify all mammal and tissue specimens. The bar codes can quickly be converted into electronic information, put into GIS layers in maps, and overlaid with other data so that we can link maps of habitat with the distribution of species. There are 47 Landsat scenes covering the state of Texas. Each scene covers an area about 115 x 115 miles (185 x 185 km), or about nine counties in the Texas panhandle. To classify land cover in each scene, we traveled to the area covered by the scene and identified the vegetation at 50 to 200 sites. The location of each site was determined with global positioning system (GPS) units by recording Universal Transverse Mercator (UTM) coordinates. The UTMs were entered into a database and incorporated into a GIS for presentation in a graphical form. The dominant plant communities at each site were classified using The Nature Conservancy's description of North American vegetation.

Texas GAP has over 10,000 miles of aerial videography flown in a north-south pattern from the Texas northern border to the Texas southern border at 1,000 feet elevation. These north-south flight lines are about 30 miles apart east to west and provide a low level, aerial view of land cover. We used the low level aerial videography and data collected on the ground to interpret the satellite scenes and classify the vegetation. Texas GAP is really large; however, it becomes even larger when linked to a project that spills over into Mexico. This project in Mexico, the Rio Grande or Rio Bravo GAP, covers the North American Free Trade Agreement (NAFTA). The 20 Landsat scenes necessary to cover the NAFTA area south of the border are larger than the state of California. When we put the Texas and Mexico projects together, they form a pretty significant project. The Rio Grande GAP is the first international GAP project and is being conducted hand in hand with Mexican agencies such as CONABIO and colleagues in Mexico. We are collaborating on the field work, the data analysis, and production of vegetation maps to be used in a GIS to build distribution maps for the vertebrate species.

Spectrum software, from Khoral, Inc., Albuquerque, New Mexico, is used to classify the hyperclustered Landsat scenes. The vegetation, represented by a particular pixel or group of pixels, is identified in the field, and the Spectrum program classifies all other pixels with that same spectral signature. We are certainly not able to go to every point in Texas, but we do go to selected points, and with Spectrum we extend our field identification of vegetation to all similar pixels and strive for 80% accuracy for classification of vegetation. We can get to about 80% with a fairly low cost; however, to get it from 80% to 100% the cost becomes prohibitively high. The goal of national GAP is to achieve 80% accuracy in classification of vegetation.

The successes of the national GAP and Texas GAP depend upon partnerships. Multiple partnerships, such as our partnerships with the Texas Parks and Wildlife Department and the Museum of Texas Tech University, allow us to acquire information on genetic biodiversity—details that go far beyond this program. Together, we are developing data including DNA libraries. Dr. Baker, his colleagues and students are collecting the museum specimens and developing the DNA libraries. We establish computer databases, containing DNA fingerprints and profiles, and link these databases to Texas GAP. Texas GAP benefits from these partnerships. The data points will be used to develop vertebrate models with site specific details and species specific projects, such as for scaled quail or mountain lions. For example, to answer questions about scaled quail distribution, graduate student, Raquel Leyva has prepared the 100-year average of precipitation in the state. These data were gleaned from 3,860 weather stations in Texas, some of which have records going back over 100 years. She placed all of these records into a database, a process which took about 18 months, and now she is able to produce maps depicting average rainfall, maximum temperature or minimum temperature for any year or series of years. With the historical precipitation, the maximum temperature, the minimum temperature available for any time frame, weather patterns can be examined for possible correlations with the abundance of scaled quail.

These databases and GIS layers can also be used to more precisely model distribution of vertebrates. For example, the piñon mouse, *Peromyscus truei*, is found in about six counties in the panhandle and in the Guadalupe Mountains. If you were to look at any earlier map showing distribution of *P. truei*, you would find the entire county, the political boundary, depicted as the range. As part of GAP, we develop models to delimit vertebrate distribution by specific information developed for each species. Is the species found in association with a certain plant, in a certain soil type, at a certain elevation, on a certain slope or aspect? These types of data are used to develop a habitat profile for each species and the habitat profile is used to build a model to predict where the species could be found. The model is used to develop a habitat specific map for each species, and then scientists knowledgeable of a particular species distribution verify accuracy of the predicted range. In an interactive process of adjustment and feedback we refine models to develop the most acceptable range map. The habitat restricted models can be quite valuable to society. People in these six counties would be concerned about how their land could be used if the piñon mouse were listed as threatened or endangered. They would be concerned about the red tape and permitting processes. Habitat-based distribution models can now be very specific; we can limit the areas of concern.

Habitat-based distribution models can now be very specific; we can limit the areas of concern.

As another example, consider the tremendous economic activity of birders all over the country as they build their life list of birds identified in the field. They want to go where the birds are, and they will spend money to get a new entry on their lists. If they have a bird distribution map that has the whole county in it, they might have to look throughout the whole county to find a specific species of bird. However, a habitat specific distribution map for a species is a far more precise product than is a county map. Elevation is an important delimiter in distribution models for many species. For example, the model for *P. truei* was limited to juniper habitat on steep slopes by including elevation in the model. To help us better view elevational changes on the southern high plains, we have prepared maps in which the vertical elevation has been highly exaggerated. Even with vertical exaggeration, the plains appear as flat as a table top. It is this type of information that we build into vertebrate distribution models that lets us draw a fine line and say this is where we find *P. truei*.

Our common goal is to place information into databases so that it may be used as tools to support decisions.

When I discussed this model for *P. truei* with Dr. Baker, he told me that some people have argued that animals collected from the Guadalupe Mountains and the panhandle may not be one and the same species. There may be two species. We don't really know the genetic diversity; we don't know how closely the two populations are related. It may take DNA probes and a DNA analysis to really have a definitive answer on this species. Building distribution models based on habitat profiles is an interactive process, and it takes both the field work and the field biologists working with GIS and GAP to develop an acceptable product. At Texas Tech University we have the most tightly linked museum and gap analysis program in the nation. We put this information into the hands of users: the professionals making natural resource management decisions, the public, school teachers, and school children. There are several products now on the Web: the Coop Unit Web page at <http://www.tcru.ttu.edu/tcru/> and the Natural Science Research Laboratory of the Museum <http://www.nsrl.ttu.edu/tmot/>. *The Mammals of Texas* by Dr. Schmidly is now on the Web. We also have the *Manual of Fish Culture*, published in 1897, on the Web. This century-old book contains 80 wonderful plates and 36 figures of various sites all over the country. The biological survey of Texas, conducted from 1895 to 1906 by Vernon Bailey, is being prepared for release on the Web. Dr. Schmidly has visited the Smithsonian and has personally examined every specimen collected by Vernon Bailey in the *Biological Survey of Texas*.

Schmidly has copies of all 1,038 photographs taken during the 1895–1906 survey. He also has copies of all of the field notes. One of those early photographs was taken in Santa Elena Canyon in Big Bend National Park. Today, the vegetation that exists in Santa Elena Canyon is quite different from that of 100 years ago. I haven't seen all of the early photographs, but undoubtedly there are pictures of the Guadalupe Mountains taken as Vernon Bailey passed through this area. When these data and photographs are placed on the Web, they will be available to everyone who has an interest. These are the types of information products we are developing. We expect these products to really make mountain islands, such as the Guadalupe Mountains, of greater value to those who live and study here and to those who will only be able to visit through the Web. We view this process as ongoing, not just another report to be filed. The information will only get better as more data are added to the databases. These electronic databases will link information resources such as geology, cultural areas, gap analysis, and vegetation. These different data layers exist today, but only in obscure reports filed away in some even more obscure bureaucratic office. Our common goal is to place information into databases so that it may be used as tools to support decisions. By placing data synthesis products into GIS layers and providing them through the Internet, people can use them to make better decisions.

If our society can accomplish that goal, we may be able to avoid the problems that ancient civilizations faced, and we are the first civilization to have the tools to make that opportunity available. As a society, we face some big problems in maintaining biodiversity and a biologically rich environment. The Guadalupe Mountains National Park is one very critical point protecting and preserving biodiversity and our quality of life. I thank you for the opportunity to share these thoughts with you.

Chapter 11

Distribution of Aquatic Invertebrates in McKittrick Creek

TIMOTHY M. GREEN, Ph.D., is a section manager for the Water Permitting and Compliance Program, Pantex Plant, Battelle Memorial Institute. He inventoried the distribution of aquatic invertebrates in McKittrick Creek and provided recommendations on the use and probable effects of rotenone in McKittrick Creek.

Introduction

McKittrick Creek in the Guadalupe Mountains National Park, Texas is a semi-isolated, perennially-flowing, discontinuous, desert-mountain stream. It flows over solid calcareous rock, cobbles, gravel, and sand. The creek is divided into three branches: North McKittrick Creek, South McKittrick Creek and Lower McKittrick Creek. North McKittrick originates in the Lincoln National Forrest of New Mexico, while South McKittrick originates high in the center of the Guadalupe Mountains. North and South McKittrick join to form Lower McKittrick Creek about 2.3 miles into McKittrick Canyon from the McKittrick Canyon Visitor Center. North McKittrick and South McKittrick flow through pine and maple forests. Lower McKittrick flows mostly through desert shrubs and shrub oak. Terrain through which McKittrick Creek flows varies from steep in North and upper South McKittrick to a gentle incline in lower South and Lower McKittrick. The creek itself is somewhat unique in that it is discontinuous and flows both above and below ground as it winds its way to the desert east of the mountains. Because of the uniqueness of this stream system it becomes an ideal location to study benthic invertebrate distributions that can be used in comparison to existing hypotheses.

At the time this study was done there had been few studies conducted on desert-mountain streams (Bane and Lind 1978; Bruns and Minckley 1980; Lind, 1969, 1971, 1979, 1982; Meyerhoff and Lind 1987a, 1987b). Only the studies by Lind and, Meyerhoff and Lind, dealt with McKittrick Creek. The study by Meyerhoff and Lind (1987b) was the only study to detail invertebrate distributions in McKittrick Creek. Meyerhoff and Lind simply discussed the relationships between substrate and detritus and continuous versus discontinuous flow. The present study investigated the effects of other factors such as habitat, current velocity, and physical and chemical aspects of the creek that might affect invertebrate distributions.

Many works have dealt with aquatic invertebrate distributions. These studies have investigated distributions in relation to habitat (McCulloch 1986, Reisen 1975); substrate and sediments (Brusven and Prather 1974, Crisp and Crisp 1974, Cummins and Lauff 1969, Egglishaw 1964, Hunt 1930, Linduska 1942, Minshall and Minshall 1977, Percival and Whitehead 1929, Rabeni and Minshall 1977, Reice 1980, Williams 1980, Williams and Mundi 1978); and current velocity, silt, detritus, and other factors (Rabeni and Minshall 1977, Minshall and Minshall 1977). Merritt and Cummins (1984) hypothesized that the ultimate factors affecting invertebrate distributions are the physical-chemical tolerance of the invertebrates to their environment. Competition and/or predation probably also play roles in invertebrate distributions (Hart and Resh 1980, Peckarsky 1980, Peckarsky and Dodson 1980, Allan 1982). All of these factors together may determine the major constraints on the distribution of aquatic invertebrates.

The concept of the river continuum was proposed by Vannote and others (1980). They noted that a downstream invertebrate community is affected by factors and conditions that exist upstream from the community. In McKittrick Creek the nature of the creek precludes the river continuum concept (Meyerhoff and Lind 1987b). McKittrick Creek's discontinuous nature, typified by stretches of above ground flow separated by areas of submerged flow, does not allow the continuous flow of material from upstream sources to down stream locations. Therefore, upstream factors should seldom have affect on down stream populations in McKittrick Creek. Meyerhoff and Lind theorized that coarse detritus would ultimately determine invertebrate distributions and are also temporal in nature (1987b).

Previous studies of McKittrick invertebrates were based on small samples. Lind (1979) collected data over a five-year period from 1967 to 1972 that resulted in approximately 11,000 individuals from 41 taxa found in three habitats during two seasons (spring and fall). Meyerhoff and Lind (1987b) obtained only 60 samples containing 16,600 individuals from 13 taxa, one habitat (pools), and one season (summer). This recent study resulted in approximately 300,000 individuals from more than 80 taxa, three habitats (riffles, runs, pools), and four seasons over a two-year period. This large number of individuals resulted in full analysis of 24 taxa and partial analysis of 44 taxa. Several taxa identified had numbers less than 0.5% of the entire population, too low a number for statistical analysis.

There is a difference in the number and type of taxa present between the three studies that have been done. McKittrick Creek undergoes periodic flash floods that alter the creek bottom and very probably the faunal composition. After Lind's study, flash floods have occurred in the late 1970s and mid-1980s, and since completion of the field work for this study floods have occurred in 1990 and 1991. Comparing the taxonomic information of the three studies reveals the differences in the taxa found (Table 1). These variations may in part be the result of flash floods. Other differences are probably more a result of the level of sampling that occurred.

Table 1. Comparison of taxonomic make-up of collections between previous studies and the present study of McKittrick Creek

Lind, 1979	Meyerhoff and Lind, 1987	Green, 1993
Cnidaria		
Chlorohydra sp.		Hydra sp.
Turbellaria		
Dugesia tigrina		Dugesia tigrina
Nematomorpha		
Gordius sp.		Gordius sp.
		Nematoda
Annelida		
Oligochaeta		
		Pristina sp.
		Lumbricus sp.
		Naididae
Mollusca		
Physidae		
		Physa sp.
		Pisidium sp.
Crustacea		
Ostracoda		
		Cytheridae
Amphipoda		
Hyallela azteca		Hyallela azteca
Copepoda		
Ectocyclops phaleratus		Cylopoida
Cladocera		
Daphnia pulex		Alona sp.
Ceriodaphnia quadrangula		

Lind, 1979	Meyerhoff and Lind, 1987	Green, 1993
Acarina		
		Acarina 1
		Acarina 2
		Acarina 3
		Acarina 4
		Acarina 5
		Acarina 6
		Acarina 7
		Collembola
Diptera		
		Dixidae
Tipulidae		
		Tipula sp.
		Hexatoma sp.
		Pedicia sp.
Heleidae		
Simulidae		
Simulium sp.		
Tendipedidae	Chironomidae	
Genus A	Psectrocladius sp.	Chironomid 1
Genus B	Nilotanypus sp.	Chironomid 2
Genus C	Conchapelopia sp.	Chironomid 3
Genus D	Microtendipes cf. caducus Townes	Chironomid 4
Genus E	Stictochironomus sp.	Chironomid 5
	Stenochironomus hilaris (?) (Walker)	Chironomid 6
	Pseudochironomus nr. richardsoni Malloch	Chironomid 8
		Chironomid 9
Tabanidae		
Tabanus sp.		Tabanus sp.
Stratiomyidae		
Euparyphus sp.		Euparyphus sp.
		Caloparyphus sp.
Ceratopogonidae		
Probezzia sp.		Ceratopogonidae
		Empedidae
		Haemerodromia sp.
Trichoptera		
Calamoceratidae		
Notiomyxia sp.	Phylloicus sp.	Phylloicus sp.
Psychomyiidae		
Odontoceridae		
Genus A (Ross)	Marilia sp.	Marilia sp.
Helicopsychidae		
Helicopsyche sp.	Helicopsyche mexicana Banks	Helicopsyche sp.
Limnephilidae		
Hesperophylax sp.	Hesperophylax sp.	Hesperophylax sp.
	Limnephilus sp.	Limnephilus sp.
Hydroptilidae		
Agraylea sp.	Hydroptila sp.	Hydroptila sp.
	Oxyethira sp.	Oxyethira sp.
	Genus A	Neotrichia sp.
		Neotrichia A
		Ochrotrichia sp.
Hydropsychidae		
Hydropsychae sp.	Hydropsychae sp.	Hydropsychae sp.
Leptoceridae		
Athripsodes sp.		Oecetis sp.
	Lepidostomatidae	
	Lepidostoma sp.	Lepidostoma sp.
	Philopotamidae	
	Wormaldia sp.	Wormaldia sp.
		Polycentropodidae
		Cernotina sp.
		Lepidoptera
		Petrophila sp.

Lind, 1979	Meyerhoff and Lind, 1987	Green, 1993
Odonata		
Zygoptera		
Agrionidae		
Argia sp.	Argia lugens	Argia lugens
	Argia plana	Argia plana
Coenagrionidae		
Archilestes sp.	Archilestes grandis (Rambur)	Archilestes sp.
Anisoptera		
Libellulidae		
	Paltothemis lineatipes Karsch	Paltothemis sp.
	Aeshnidae	
	Aeshna umbrosa Walker	Aeshna sp.
Hemiptera		
Belostomatidae		
Belostoma sp.		
	Gerridae	
	Gerris remigis Say	Gerris sp.
		Trepobates sp.
		Limnoporus sp.
	Veliidae	
	Rhagovelia distincta (?) Champion	Rhagovelia sp.
	Microvelia sp.	Microvelia sp.
	Naucoridae	
	Ambryssus buenoi Usinger	Ambryssus sp.
		Cryphocricos sp.
	Corixidae	
	Graptocorixa abdominalis (Say)	
	Notonectidae	
	Notonecta lobata Hungerford	Notonecta sp.
Ephemeroptera		
Baetidae		
Baetis sp.		Baetis sp.
Leptophlebiidae		
Choroterpes sp.		Choroterpes sp.
		Caenidae
		Caenis sp.
Coleoptera		
Psephenidae		
Psephenus sp.		
Chrysomelidae		
Neohaemonia sp.		
Elmidae		
	Dubiraphia sp.	Heterelmis sp.
	Macrelmis sp.	Elsianus sp.
	Neoelmis sp.	Neoelmis sp.
		Stenelmis sp.
		Microcylloepus sp.
		Ordobrevia sp.
		Hexacylloepus sp.
Curculionidae		
		Hyperodes sp.
		Lixus sp.
Georyssidae		
Georyssus sp.		
	Dytiscidae	
	Hydroporus pseudovilis (?) Young	Hydroporus sp.
	Hydroporus dimidiatus Geminger and Harold	Neoclypeodytes sp.
	Neoclypeodytes discretus Sharp	Laccophilus sp.
	Laccophilus horni Van Den Branden	Liodessus sp.
	Thermonectes marmoratus marmoratus Hope	Thermonectes sp.
		Derovatellus sp.
	Hydrophilidae	
	Tropisternus sp.	Berosus sp.
	Dryopidae	
	Helichus triangularis Musgrave	Helichus sp.
	Helichus confluentus Hinton	

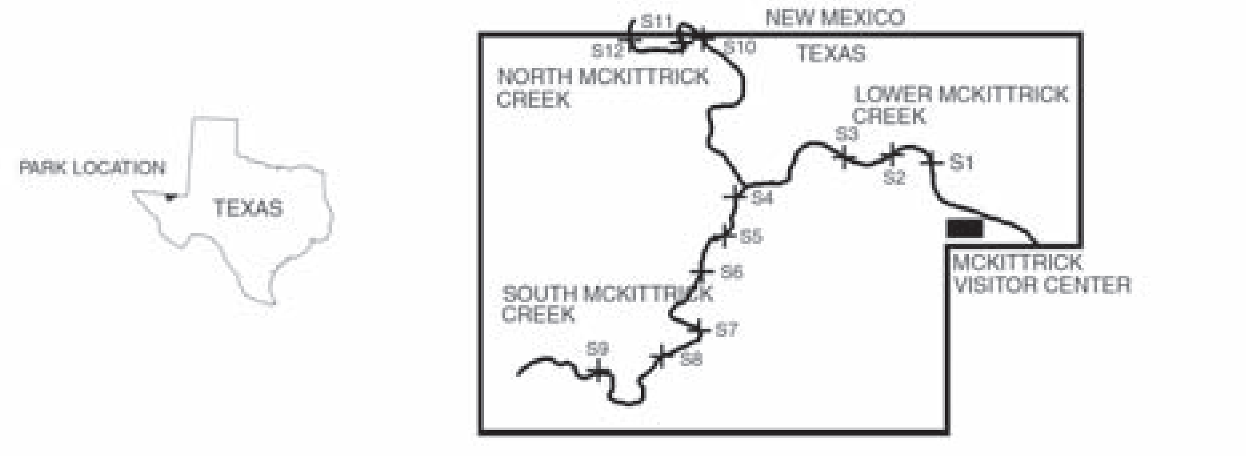

Figure 1. Location of sampling sites along McKittrick Creek.

Materials and methods

Twelve sampling sites were chosen along North, South, and Lower McKittrick creeks. Each site was chosen for its location along the creek for its accessibility (Figure 1). All sites were sampled approximately every two months (weather permitting) over a two-year period with a shift of one month after the first year of collecting. This shift resulted in collections during every month of the year.

Three sampling sites were located along Lower McKittrick Creek (S1, S2, and S3), six sites along South McKittrick Creek (S4, S5, S6, S7, S8, and S9), and three sites along North McKittrick Creek (S10, S11, and S12). Trout are present at all three sites in Lower McKittrick.

Vegetation along Lower McKittrick varies from desert shrub and shrub oak (*Quercus* sp.) at S1, to bigtooth maple (*Acer grandidentatum*) and juniper (*Juniperus* sp.) at S2, to sawgrass (*Cladium jamaicense*), juniper, and deciduous trees at S3. Trout are present at all three sites in Lower McKittrick. The creek bottom varies from cobble, sand, and gravel at S1; to gravel, cobbles and coarse detritus at S2; to gravel and cobble in riffles and runs, and sand and fine particulate matter in ponds at S3.

Trout are also present from S4 to S8 but are absent from S9. Vegetation varies from pine and maple at S4 (away from the creek) and S5, to maple, pine, horsetail (*Equisetum laevigatum*) and watercress (*Rorippa nasturtium-aquaticum*) at S6, to sawgrass and pines at S7 and S8. S9 is located high in South McKittrick and is lined with boulders. Vegetation at this point tends to be pine forest and maple located on the mountain slopes. The creek flows over travertine at S4, cobble, gravel, and sand at S5 and S6. S6 is located at the spring of the lower portion of South McKittrick Creek. The creek bottom at S7 is composed of cobble, gravel, and sand, but large quantities of seeds and other organic matter is present. S8 has an area of solid rock with the remainder of the area being cobble and gravel. The creek at S9 flows over solid rock to a cobble-lined pool.

Sunfish were present at S10 in 1987 but were absent in 1988. No fish were present at S11 or S12. Vegetation in North McKittrick generally consisted of sawgrass, maple, and pine trees. The creek flows over cobble and gravel at S10 and contains large quantities of coarse organic matter. At S11 the creek flows over cobble, gravel, and sand. The creek flows over solid rock into gravel-lined pools at S12.

Physical and chemical characteristics of the creek were sampled at each location during each visit. Water temperature was measured with a centigrade thermometer at each location and with a semi-permanent maximum-minimum thermometer at S1, S3, S4, S6, S7, S9, S10, and S12. Conductivity and pH were recorded using pocket mini-meters, and dissolved oxygen was recorded using a portable oxygen-meter adjusted for altitude, temperature, and conductivity. Water samples were taken and analyzed for total alkalinity, total hardness, calcium hardness, magnesium hardness, sulfate, nitrate-nitrogen, and total phosphates. Surface water velocities were measured using a neutrally buoyant vial in each of the three habitats (riffle, run, and pool). This method of measuring water velocity was necessary because of the shallowness of the creek in most locations.

Invertebrate samples were taken by combining two 929-square-centimeter samples taken from each habitat using a Surber stream bottom sampler. Although this method is not the most accurate (Usinger and Needham 1954, Needham and Usinger 1956), it was preferred for this study because of the nature of the substrate and transport requirements. Samples were stored in plastic bottles and fixed with a 10% formalin solution containing rose bengal. In the laboratory, samples were washed through a standard soil sieve set to remove detritus. Material left on sieves with mesh sizes 230, 120, and 60 was placed in a gridded pan and subsampled using rapid bioassessment protocols established by the Environmental Protection Agency (EPA) (Plafkin et al. 1989). This usually resulted in between 90 and 300 individuals being sampled. Subsamples were placed under a dissecting microscope and individuals identified to lowest taxonomic level possible using available taxonomic keys (Merritt and Cummins 1984, Pennak 1978, Burch 1975). Total number/taxon was estimated using the formula:

$$T = t \times n / N$$

Where T is the total numbers/taxon, t is the number/taxon counted, n is the number of cells sampled in the gridded pan, and N is the number of cells in the sampling pan. Single individuals of any species were quickly picked from the sample by scanning the pan. Specimens were then preserved by taxon in vials using 70% ethanol.

Statistical analysis included analysis of variance (ANOVA), multiple linear regression, Chi-square, cluster analysis, principle components analysis, diversity, and evenness. These analyses were completed using BioCalc2, True Epistat, and Systat.

Cluster analysis was used to determine distributional classification of sites and the 44 most common species. Taxonomic classification was based on taxon distribution among the 12 sites, and site classification was based on the taxonomic make up of the sites using the 44 most common species. Distributional analyses, by means of ANOVA, were done for each of the 24 major taxa and on diversity indices for sites. Principal components determined from physical-chemical data were used in multiple linear regression to determine factors affecting invertebrate distributions. Multiple linear regression was also performed using raw physical-chemical data and Log10 taxonomic data to determine which physical-chemical factors had effects on invertebrate distributions.

Results

A total of 87 taxa were identified and quantified in this study. Of the 87 taxa only 24 were present in sufficient numbers to complete statistical analysis. The other taxa were used either in cluster analysis or were simply reported as being present.

Individual species or taxonomic groups showed variable distributions depending on the group and relationships with other invertebrates, habitat, physical-chemical factors, and stream segment (Green 1993). When data for all 24 taxa were combined and analyzed using ANOVA, significant distribution among the three habitat types is seen. There is also significant spatial variation between stream segments. They are most abundant in Lower and South McKittrick with S4, S5, S6, and S7 having the largest groupings of taxa.

Shannon-Weiner diversity was calculated for each site and each habitat at each site. Site diversity varied between sites and between habitats at sites. Highest site diversity was seen at S5 with H = 2.7398. Diversity in riffles indicated that the riffles at S5 had the highest value of 2.3170. S3 had the highest diversity in run habitat with a value of 2.4333. Pool diversity was highest at S5 with a value of 2.4957. Runs were more diverse than either pools or riffles. The lower South McKittrick section of the creek was more diverse than the other sections with an index of 2.5763. This section contains S5. Evenness values indicate that Lower and South McKittrick have significantly higher mean evenness values than North McKittrick.

Cluster analysis was performed on the taxonomic data in two ways. The first was using the 44 most common taxa to determine their distribution within the 12 sites. The second way was to cluster the 12 sites based on distributions of the taxa among the sites. Species clustering resulted in 11 cluster groups, three of which contained the majority of the 24 major taxa. Site clustering resulted in three clusters that included S5 and S6 in the first cluster, S2, S3, S4, S7, S8, and S9 in the second cluster, and S1, S10, S11, and S12 in the third cluster (Table 2).

Distribution of 13 taxa was somewhat affected by physical-chemical factors as shown by regression analysis. Of the various physical-chemical variables water velocity was important in the distribution of 11 groups. Four taxa had a temperature variable and six taxa had a chemical component included in their regression

Discussion

Invertebrate distributions continue to intrigue biologists. The river continuum concept proposed by Vannote and others (1980) has resulted in numerous papers concerning the validity of the concept, including the present paper. The river continuum concept suggests that distributions of aquatic invertebrates are determined for the most part by the physical and chemical conditions that exist in the upper portions of a stream system. Materials and processes are graded from upstream to downstream, which would result in variations in invertebrate distributions. The present study suggests that the river continuum concept is not valid in discontinuous desert streams, such as McKittrick Creek.

In discontinuous streams the accumulation of materials due to downstream flow does not occur to the extent that it does in continuous streams. Stream sections are too short for transport of sufficient quantities of organic material that would result in varying microhabitats, which would cause variations in invertebrate communities. The subsurface flow that occurs in McKittrick Creek prevents the continual downstream transport of organic material and results in uniformity within the physical and chemical variables. In McKittrick Creek the detritus tends to accumulate within the pools of each stream section and may play a role in distributions within pools (Meyerhoff and Lind 1987b). Distributions within McKittrick Creek appear to be influenced more by habitat, location, biotic interactions, and to a lesser extent, physical and chemical variables (Green 1993).

Substrate and detritus as shown by Meyerhoff and Lind (1987b) influence distributions. Habitat plays a major influence in distributions. Differences among habitats are largely a measure of water velocity and the ability of the stream to carry organic matter. In this study various groups are distributed based on habitat preferences. Twelve taxa were found in riffles with three of these limited to the riffle habitat. Sixteen groups were found in runs with three being primarily found in this habitat. Pools tend to be more diverse with 18 groups being abundant of which six are primarily found in pools.

Interspecific interactions play a somewhat major role in invertebrate distributions. Regression analysis consistently included two or more taxa within the regression more often than other variables. Interactions appeared to be due to many different reasons including parasitism, niche separation within the same habitat, exclusion, competition, and preda-

Table 2. Classification of taxa and sites. Horizontal classification is by species composition of sites. Vertical classification is by distribution among sites. * = 1 of 24 common taxa. Similar sites are clustered together across the top of the table with a space between clusters. The clustered taxa are shown down the left side of the table with blank rows separating the clusters.

SPECIES	S6	S5		S4	S2	S3	S7	S8	S9		S1	S10	S11	S12
Ochrotrichia	127	8		27	27	0	0	0	8		5	23	13	33
Lepidostoma	533	292		32	18	33	129	2	7		0	0	2	2
Hydra	601	441		59	8	5	76	34	34		1	1	0	1
Naididae	5	53		86	19	51	9	39	135		17	0	2	0
Cyclopoida	167	213		100	52	62	129	71	94		9	0	16	8
Chironomid 5*	113	670		289	59	323	206	45	28		2	3	13	0
Oxyethira*	219	2242		634	73	379	377	81	121		19	6	18	0
Stenelmis	8	50		0	6	2	35	87	361		36	39	71	7
Elsianus	12	28		4	6	11	31	99	315		27	94	31	10
Helichus	14	30		26	5	30	44	9	100		13	32	7	1
Wormaldia	22	127		14	122	264	184	35	15		34	36	10	1
Tabanus	53	44		35	84	129	100	21	28		38	14	3	24
Haemerodromia	8	62		33	96	71	103	33	5		65	7	29	18
Paltothemis	9	29		64	73	30	13	121	43		14	37	29	13
Acarina 4	7	31		41	15	38	167	122	54		37	27	34	15
Marilia	4	78		56	66	34	329	112	224		41	89	80	109
Neoelmis	1	87		3	535	24	184	61	136		17	10	19	1
Microcylloepus	0	14		1	10	15	94	19	37		2	17	92	2
Neotrichia A	0	3		27	17	21	78	36	146		5	28	15	2
Argia lugens*	20	0		120	119	170	411	284	116		38	58	58	53
Euparyphus	1	3		132	164	5	4	5	15		23	71	22	47
Liodessus	1	0		14	39	0	4	21	57		5	14	50	29
Caloparyphus*	1	38		2291	2064	123	100	570	434		155	682	276	1982
Hexatoma	13	266		586	83	275	74	108	307		368	13	6	18
Alona*	72	417		432	188	113	343	1023	352		40	27	6	19
Pristina*	126	343		155	499	299	390	333	229		63	35	45	31
Hydropsychae*	119	443		92	128	219	191	36	75		18	31	60	6
Physa*	475	618		837	195	156	76	126	43		17	54	32	93
Chironomid 6*	653	636		196	288	484	199	201	55		110	143	213	143
Acarina 1*	1189	452		82	105	158	208	76	217		119	63	45	24
Cytheridae*	4992	2138		103	556	874	345	49	194		242	203	43	51
Caenis*	143	972		751	76	132	1705	208	668		4	95	337	186
Hyallela azteca*	3773	2878		1874	512	3725	1235	289	129		309	10	30	110
Chironomid 3*	4273	3056		564	338	250	1239	351	413		71	69	260	166
Dugesia tigrina*	1943	1284		551	581	946	1130	724	685		293	246	267	252
Argia plana*	3367	2108		647	1072	1384	1495	881	224		549	402	272	86
Chironomid 2*	1533	2261		1388	495	712	963	963	737		293	275	183	40
Choroterpes*	1164	3702		321	474	1128	3301	2247	1737		2958	305	418	142
Chironomid 1*	885	3806		3097	2080	1920	3233	1656	2804		717	517	606	710
Chironomid 4	3107	5464		7565	2983	1957	2894	1646	2328		817	1373	729	634
Baetis	7032	7536		2211	2258	3666	3274	2784	2129		439	1915	2814	1459
Simulium	4357	4534		1645	1342	1759	3476	1549	674		332	499	1737	921
Hydroptila	714	764		1756	1489	963	1093	2267	266		1042	2786	1965	1246
Ceratopogonidae	179	3004		1327	2444	1384	5570	2335	872		1693	2337	1525	8712

tor-prey relationships. These relationships result in multiple taxa being consistently present together in samples.

Physical and chemical variables such as water velocity, temperature, conductivity, and pH play minor roles in determining the distribution of some aquatic species. Thirteen taxa had physical and chemical variables within their regression, but the included components were not as important as other variables.

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Chapter 12

Forensic Entomology Meets the Guadalupe Mountains

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Introduction

Forensic entomology is the application of arthropod evidence to legal investigations (Keh 1985, Hall 1990, Catts and Goff 1992, Goff 1993), and has been divided into three main categories: urban entomology, stored products entomology, and medicolegal entomology (Lord and Stevenson 1986). The focus of this article is medicolegal entomology, which deals with entomological evidence recovered from crime scenes, usually involving a felony homicide or other violent crime, and the application of this evidence to a criminal or civil investigation (Hall 1990, Catts and Goff 1992). Medicolegal entomology has become the most widely recognized category and is synonymous with forensic entomology throughout the scientific community and the public in general (Goff 1993).

The earliest written record of the use of insects to solve a homicide is cited in a 13th-century Chinese manual on forensic medicine (Keh 1985). This manual, *The Washing Away of Wrongs*, was written by Sung Tzu in A.D. 1235 (McKnight 1981, Smith 1986, Turner 1991, Catts and Goff 1992, Goff 1993). In this account, the victim died of wounds inflicted by a farmer's sickle. The inquest officer ordered each farmer to place his sickle on the ground in the center of the village. Flies were attracted to only one sickle, the one where traces of blood remained. The owner of the sickle subsequently confessed his crime.

The beginning of the modern era of forensic entomology is marked by the works of several European scientists, including Berget, Broudel, and Yovanovitch (Catts and Goff 1992). Their contributions were made in the late 19th century and were followed by Megnin in 1894, with the publication of *La Faune des Cadavres: Application L'Entomologie a la Medicine Legale* (Turner 1991, Catts and Goff 1992, Goff 1993). Megnin was the first to demonstrate the importance of entomological data in legal investigations. Megnin also proposed that corpses undergo a series of stages of decay and that each stage is characterized by a unique arthropod assemblage (Hall 1990). This was quite a novel concept at the time, and even today researchers are still conducting decomposition studies in order to document the succession of arthropods at a corpse (Tantawi et al. 1996, Richards and Goff 1997).

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Decomposition research: collecting baseline data

Decomposing remains provide a unique resource to many organisms, including bacteria and fungi, arthropods, and vertebrate scavengers (Goff 1993). A thorough knowledge of the ecology of the fauna associated with remains is an essential foundation of forensic entomology. Arthropods compose the greatest proportion of this fauna, and insects are the most abundant component of the arthropod group, both in species diversity and absolute number of individuals (Goff 1993). Arthropods play several roles at the carcass, and generally four groups are recognized (Smith 1986, Turner 1991, Catts and Goff 1992, Goff 1993):

Necrophagous species. This group includes taxa which feed directly on the remains. This group is primarily composed of Diptera (flies in the families Calliphoridae, Sarcophagidae, and Muscidae) and Coleoptera (beetles in the families Silphidae and Dermestidae). This group is by far the most important in establishing a time of death or postmortem interval.

Predators and parasites of necrophagous species. This group has been identified as second in importance to forensic entomology. This group includes the Hymenoptera, wasps which parasitize immature stages of Diptera. Also included in this group are the larvae of Calliphoridae, which are facultative predators and will prey on the larval stages of other species present at the carcass. Another major group is beetles in the families Stayphilynidae, Silphidae, and Histeridae. These beetles prey on dipteran larvae.

Omnivorous species. This group contains species that feed on both the carcass and on the arthropods present. Hymenoptera (wasps and ants) are a major component of this group. Ants often feed on dipteran eggs and first instar larvae, and on the liquids and soft tissues of the carcass. Wasps also consume liquid and soft tissues of the carcass and in addition, prey on adult flies associated with the carcass. Although this group is not recognized to be as important as the two groups previously discussed, the presence of such species can deplete the population of necrophagous species present at the carcass and thus delay the decomposition process (Early and Goff 1986, Richards and Goff 1997) and/or alter arthropod succession patterns (Stoker et al. 1995). This may have serious implications in determining a postmortem interval, and a forensic entomologist should be aware of the presence and impact of such species.

The history of carrion research involves documenting arthropods associated with decomposition, describing the ecology of the carrion community and understanding the biology of these arthropods.

Adventive or incidental species. This category includes arthropods found using the carcass as an extension of their normal habitat, such as spiders, centipedes, mites (Acari) or springtails (Collembola). They may opportunistically use the carcass as shelter or as a resting place. The forensic importance of such species at a carcass is low but is always documented during decomposition studies.

The history of carrion research involves documenting arthropods associated with decomposition, describing the ecology of the carrion community, and understanding the biology of these arthropods (Doube 1987, Catts and Goff 1992). Two excellent reviews of the ecology of the carrion habitat as an ephemeral resource have been published (Beaver 1984, Doube 1987). Many studies have documented varying stages of decomposition and the fauna associated with each stage (Bornemissza 1957, Reed 1958, Payne 1965, Coe 1978, Early and Goff 1986, Tullis and Goff 1987, Tantawi et al. 1996), faunal differences in this community among contrasting habitats in desert, tropical, and temperate regions (Bornemissza 1957, Walker 1957, Reed 1958, Payne 1965, Cornaby 1974, Johnson 1974, Mckinnerney 1978, Rodriguez and Bass 1983, Early and Goff 1986, Braack 1987, Tullis and Goff 1987, Richards and Goff 1997), and seasonal changes in the carrion arthropod community within a single habitat (Braack 1987, Putman 1978a, 1978b).

The collection of baseline data is the foundation of forensic entomology. The community of arthropods that colonizes remains is quite diverse and requires meticulous investigation. Numerous baseline decomposition studies have been conducted and various types of animal carcasses have been used, including guinea pigs (Bornemissza 1957), lizards and toads (Cornaby 1974), rabbits (Denno and Cothran 1975, Tantawi et al. 1996), cats (Early and Goff 1986), dogs (Reed 1958), pigs (Payne 1965, Tullis and Goff 1987, Hewadikaram and Goff 1991, Richards and Goff 1997), sheep (Denno and Cothran 1975), impala rams (Braack 1987), and elephants (Coe 1978). Although some of these studies were conducted in the interest of ecology and not for forensic purposes, a major concern in structuring most decomposition studies is the choice of animal used as a surrogate model for humans. The domestic pig, *Sus scrofa* L., provides the most accurate extrapolation from field studies to human remains and has been used extensively in such studies (Goff 1993). The size, skin, and hair of the domestic pig approximate that of a human, as does the chemical composition of the muscle tissue (Erzinclioglu 1986). However, many have used other animals out of practical considerations.

The spectrum of topics addressed in forensic entomology has grown in recent years. The assumption that Diptera arrive immediately to the corpse and begin depositing eggs or larvae is specious. Forensic entomologists must bear in mind that the estimate they establish is the duration of arthropod activity and not necessarily the time since death (Catts and Goff 1992). There are a number of situations that occur which delay arthropod access to a corpse, and this has been the focus of many studies. For example, Goff (1992) determined that the wrapping of a corpse in two layers of blankets delayed invasion by flies in the family Calliphoridae by 2.5 days. Others studies are currently examining the effects of hanging, burning, submergence, and/or burying of a carcass on arthropod colonization, succession, and developmental patterns. Any of which can cause these patterns to deviate from those observed during baseline decomposition studies. A forensic entomologist must know what impact such situations have on the estimation of a postmortem interval.

Applications of arthropod evidence

There are many ways in which entomological evidence can be applied to a legal investigation. For example, arthropods have been used in criminal and civil investigations to: (1) determine time of death, (2) serve as evidence of relocation of a corpse, and (3) serve as toxicological specimens (Greenberg 1991, Catts and Goff 1992, Goff 1993).

The challenge a forensic entomologist is most likely to encounter is to determine a time of death or postmortem interval for human remains. There are two main reasons why insect evidence is so useful when determining a postmortem interval. First, the insects, usually blow flies in the family Calliphoridae, are the first to arrive at a corpse and will usually lay their eggs or deposit their larvae within a few hours, sometimes within even a few minutes after arrival (Catts and Goff 1992, Goff 1993). A biological clock is started at the time the eggs are laid and is interrupted when the body is found and the forensic entomologist collects specimens from the body or surrounding area. It is now the forensic entomologist's job to determine how long the clock has been running; in other words, to determine the age of the specimens found at the crime scene, whether they are eggs, larvae, or pupae. Developmental rates vary among species associated with carrion and there have been numerous studies conducted in order to establish such baseline data at controlled temperatures and humidities (Kamal 1958, Zumpt 1965, Nuorteva 1972, Nuorteva 1977, Busvine 1980, Goodbrod and Goff 1990, Greenberg and Tantawi 1993, Wells and Kurahashi 1994, Byrd and Butler 1996).

Arthropods have been used in criminal and civil investigations to: 1) determine time of death, 2) serve as evidence of relocation of a corpse, and 3) serve as toxicological specimens.

Temperature is a key element controlling decomposition. There are two aspects of temperature which must be considered. Ambient environmental temperature is crucial in determining the activity of adult flies. The flies will not deposit eggs or larvae if the temperature is not above 20°C (Goff 1993). Therefore, a forensic entomologist must obtain weather data at the crime scene—and from several days prior to and following the discovery of the crime scene (Turner 1991). The second aspect to be considered is the internal temperature of the maggot mass if present on the corpse. This is the temperature at which the larvae develop and will determine the rate at which they grow. There is an increase in temperature even with small (>4 larvae/gram of substrate) maggot feeding masses (Goodbrod and Goff 1990). However, there is little evidence indicating a direct relationship between ambient environmental temperatures and the actual temperature experienced by large masses of developing maggots (Turner and Howard 1992, Goff 1993). Richards and Goff (1997) found that the temperature in the core of a maggot mass can exceed the ambient temperature by 26°C. Both aspects must be considered when the forensic entomologist processes the crime scene.

Several considerations and techniques have been put forth to estimate the age of Diptera larvae (Williams 1984, Erzinclioglu 1990, Goff 1993, Wells and LaMotte 1995). Killing and preservative solutions can affect larval size. It has been documented that the various solutions used in collecting and preserving insect specimens can cause varying degrees of shrinkage, resulting in an underage error from 9.7 hours up to 28.8 hours (Tantawi and Greenberg 1993).

Insects or other arthropods impact forensic science in that they may serve as alternate toxicological specimens when tissues that are taken normally for such analyses are not available or have decomposed to an unsuitable state.

The second way arthropod evidence is used to determine a postmortem interval is based on the succession pattern of the arthropods which colonize the remains. This sequential colonization has been documented to be predictable (Catts and Goff 1992). The utility of colonization studies is dependent on rigorous baseline decomposition studies. During each decomposition study, the arrival and departure dates are noted for each species that visits the carcass. This information may vary dramatically among habitats even though the same species are involved. This stresses the need for decomposition studies to be conducted in a variety of habitats.

The presence of drugs or other toxins or contaminants in the tissues of human remains impact forensic entomology and forensic science in general, and this area of forensic entomology has been termed entomotoxicology (Goff and Lord 1994). As mentioned previously, one way a postmortem interval is established is based on the life cycle of the arthropod, especially those in the order Diptera, families Calliphoridae, Sarcophagidae, and Muscidae (Goff and Lord 1994). The larvae feed on the tissues of decomposing remains and ingest the drugs or toxins contained in these tissues as they feed. Nuorteva and Nuorteva (1982) recovered mercury from maggots of various species of Calliphoridae which fed upon fish containing varying amounts of mercury. The mercury was retained throughout the larval stage and was detectable in the adult forms. The experiment was carried one step further when staphylinid beetles were fed maggots which had fed upon fish contaminated with mercury. Staphlylinid beetles frequent carrion and commonly feed on immature Diptera, and a bioaccumulation of mercury was observed in these predatory beetles. Other studies have documented the effect of various drugs on the developmental rate of the immature insects feeding on the contaminated tissues, including malathion (an organophosphate) (Gunatilake and Goff 1989), cocaine and benzoylecognine (Goff et al. 1989), heroin (as morphine) (Goff et al. 1991), amitriptyline (Goff et al. 1993), phencyclidine (Goff et al. 1994), and ecstasy (3,4-Methylenedioxymethamphetamine) (Goff et al. 1997). All of the above studies indicate that different drugs either accelerate or retard different stages of development and confound a determination of a postmortem interval.

Insects or other arthropods impact forensic science in that they may serve as alternate toxicological specimens when tissues taken normally for such analyses (blood, organs or urine) are not available or have decomposed to an unsuitable state (Goff and Lord 1994). There have been numerous studies conducted to determine the presence of drugs in fly larvae, pupae, pupal cases and adults (Beyer et al. 1980, Nuorteva and Nuorteva 1982, Introna et al. 1990, Kintz et al. 1990, Nolte et al. 1992, Goff et al. 1993, Goff et al. 1994, Goff et al. 1997) as well as beetle exuviae (Miller et al. 1994). Documentation of the presence of drugs can provide evidence of suicide or accidental overdose for a badly decomposed body (Beyer et al. 1980, Gunatilake and Goff 1989, Lord 1990) or even provide information on the geographic origin of a body by examining varying levels of mercury poisoning based on where a person lives (Nuorteva 1972). Current research areas include further basic studies documenting the effects of drugs on the developmental rates of various insect species associated with carrion and quantitative techniques to determine concentrations in the original tissues based on the levels measured in the insect specimens.

Arthropod evidence also has been used to associate suspects with a crime scene. For example, a team of investigators from Ventura County, California, visited a crime scene and nearly all of the personnel processing the scene received bites characteristic of a chigger in the genus *Eutrombicula* (Webb et al. 1983, Prichard et al. 1986). Interestingly enough, the suspect which was apprehended also had present on his body the characteristic lesions produced by bites of the same chigger. It was previously presumed that chiggers did not occur in southern California, so a team of entomologists conducted an extensive survey of the area surrounding the crime scene and recovered specimens of *Eutrombicula belkini*. The suspect denied having been anywhere near the crime scene, denied even having left the city limits, and claimed the last time he was in contact with the victim was at her home on the night she disappeared. It just so happened that the suspect chose to dispose of the body in the only area infested with this species of chigger in approximately 100 miles. He was convicted and sentenced to life in prison without the possibility of parole.

Blood-feeding, or hematophagous, arthropods also can be used to associate suspects with a crime scene. Replogle et al. (1994) were able to recover human DNA from louse excreta. They allowed crab lice, *Pthirus pubis* (L.), to feed on either the inner thigh or calve of several volunteers. Lice fecal pellets were collected from each volunteer and analyzed via the application of amplified fragment polymorphism (AMP-FLP) to amplified products of polymerase chain reaction (PCR). They used two human DNA markers and compared the results from the fecal pellet analysis to a saliva sample taken from each volunteer. They were able to identify each individual host of this blood feeding arthropod. The above research was prompted by an actual rape-murder case, where the perpetrator, infested with crab lice, left behind a valuable clue, a sample of his DNA.

Current research in Guadalupe Mountains National Park

Entomological evidence has provided information regarding the postmortem relocation of human remains. Law enforcement personnel cannot assume that the place in which the body is discovered is the same as the place of death. Blow flies are frequently the first insects to arrive at a corpse and deposit eggs or larvae, and this acquired arthropod fauna is often transported along with the corpse (Byrne et al. 1995). Information regarding relocation of human remains may lead investigators to the primary crime scene, where additional evidence can be recovered, providing a critical link between victim and perpetrator.

Currently, there are three methods proposed to detect relocation of a corpse. Goff (1991) reviewed 35 cases of human remains recovered in both indoor and outdoor settings on the island of Oahu in the Hawaiian Islands. He demonstrated there are specific arthropod taxa which are restricted to each setting. For example, if an arthropod species known to colonize remains in an indoor setting is recovered from a corpse found outdoors, this will indicate to law enforcement personnel that the body was transported from an indoor setting to an outdoor setting. Another method used to determine relocation following death is based on the natural geographic range of insect species associated with carrion (Smith 1986, Hall 1990, Lord 1990, Goff 1993). If the corpse has been transported across a natural boundary, specimens collected from the remains may be foreign to the area where the body was discovered. The third, and most recently proposed technique, involves the use of insect cuticular hydrocarbons. Cuticular hydrocarbons are lipids found on the outer surface of insects, and function to reduce water loss and serve in chemical communication (Chapman 1982). Cuticular hydrocarbons have been demonstrated to be species-specific and have shown that populations of the same species, inhabiting distinct geographic regions, have unique cuticular hydrocarbon profiles (Kruger and Pappas 1993). Studies of the individual components of the cuticular hydrocarbons and their variation with age, sex, or diet in various Diptera have been conducted

Entomological evidence has provided information regarding the postmortem relocation of human remains.

(Louloudes et al. 1962, Tyndale-Biscoe and Kitching 1974, Trabalon et al. 1990). Byrne and others (1995) extracted cuticular hydrocarbons from individual *Phormia regina*, the black blow fly, from three geographic locations in the United States. They found they could discriminate among populations and sexes using this technique and suggest it as a potential tool for use in forensic entomology.

Evidence may be recovered, which suggests that individual flies associated with the remains originated elsewhere, and thereby, indicating movement of the corpse.

Current research within Guadalupe Mountains National Park is designed to investigate the potential of a fourth method to detect postmortem relocation of human remains, using geographic variation in morphology among populations of carrion blow flies. Nearly all blow fly species used in forensic investigations are cosmopolitan in distribution. In such cases, indication of relocation may go undetected and critical evidence may not be recovered from the primary crime scene. Therefore, if significant morphological variation can be detected among populations of cosmopolitan species, then evidence may be recovered, which suggests that individual flies associated with the remains originated elsewhere, and thereby, indicating movement of the corpse.

The objectives of the current ongoing research are to determine the amount of intraspecific variation among populations of blow fly species in Texas and to determine which characteristics most contribute to morphological discrimination. Research will continue within Guadalupe Mountains National Park over the next three years to investigate temporal or year-to-year variation in morphology. The data collected from Guadalupe Mountains National Park will be joined together with data collected from other locations in west and central Texas in order to understand geographic variation among populations of blow fly species associated with carrion.

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Chapter 13

The Native Bees of Guadalupe Mountains National Park: a Preliminary Assessment

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Mention bees and the first thing likely to come to mind are honeybees. But honeybees are not typical of North American bees. They are not native, having been brought over by early European colonists. Furthermore, most North American bees are solitary, not social. They are not perennial and they do not produce honey. Yet they play a vital role as mediators of pollen across a wide array of natural landscapes (Paxton 1995, Neff and Simpson 1993). Our best estimate is that there are nearly 4,000 species of bees in the United States. And, while we have a rough idea of overall bee diversity, we have only a limited idea of distribution and behavior patterns. To ensure conservation of this rich pollinator heritage we need to know the bee fauna. We need to inventory the species and determine their distributions and habits.

Just as early cartographers were forced to leave large areas on their maps blank, so there remain uncharted regions on the entomological map. One such area is west Texas, including Guadalupe Mountains National Park. Here I present preliminary results, which though based on limited data, suggest a rich bee fauna for this uncharted region. Our knowledge of bees in the park is based on only three collections made in three separate years, once each in April, May, and in September, for a total of only seven collecting days. This is admittedly a very limited and inadequate sample. Here I present the results from this preliminary data that hint at a very rich and diverse fauna, give some sense of the biological and historical factors that might contribute to this diversity, suggest directions for future research, make predictions about the fauna, and briefly address the importance of bees in natural ecosystems.

The known bee fauna of Guadalupe Mountains National Park includes five of the six families of bees found in North America. Only Melittidae is so far undetected; I would expect it to be found with more systematic sampling. Thirty-nine genera are presently recorded from the park (Table 1), more genera than are present in all of New England, with 30 additional genera likely to occur within its boundaries. The species diversity (145) is likewise substantial. As a further indication of the richness of the fauna, 13 of these species are new. Some of these new species have been found elsewhere; others are presently known only from the park. Finally, the presence of *Dufourea boharti*, a species that was previously only known from central Mexico, is a great surprise.

Bees possess a great diversity in size and color, and this is certainly true of the Guadalupe fauna. They range from diminutive pollinators only three-millimeters long, to the highly visible carpenter bees at more than three-centimeters long, which are common in the canyons of the region. Black is the dominant ground plan, but some bees have a red abdomen, others are variously marked with white on yellow, or may be partly to entirely bright green or blue.

What are the factors that might foster this rich array of bees? The first of these is different lifestyle patterns. The majority of the bees are solitary; that is, a female makes a nest and provides for her offspring without any assistance from other individuals. Social species—repre-

Family Colletidae

Colletes bryanti
Colletes gilensis
Colletes kincaidii
Colletes sphaeralceae
Hylaeus asininus
Hylaeus episcoplais coquiletti
Hylaeus n. sp. aff. cookii
Hylaeus personatellus
Hylaeus wootoni

Family Halictidae

Agapostemon texanus
Agapostemon tyleri
Augochlorella neglectula
Augochlorella striata
Dufourea boharti
Dufourea pulchricornis
Halictus ligatus
Halictus tripartitus
Lasioglossum (Dialictus) sp. 10
Lasioglossum (Dialictus) sp. 23
Lasioglossum (Dialictus) sp. 29
Lasioglossum (Dialictus) sp. A
Lasioglossum (Dialictus) sp. B
Lasioglossum (Dialictus) sp. F
Lasioglossum (Dialictus) sp. G
Lasioglossum (Dialictus) sp. T1
Lasioglossum (Dialictus) sp. T2
Lasioglossum (Evylaeus) sp. A
Lasioglossum (Evylaeus) sp. B
Lasioglossum clematisellum
Lasioglossum comulum
Lasioglossum lampronotum?
Lasioglossum morrilli
Lasioglossum petrellum
Lasioglossum pictum
Lasioglossum pruinosiformis
Lasioglossum ruidosensis
Lasioglossum sisymbrii
Lasioglossum tegulariformis
Sphecodes (Arctosphecodes)asclepiadis gr.

Family Andrenidae

Andrena imitatrix
Andrena jessicae
Andrena pecosana
Andrena prunorum
Andrena simulata?
Andrena sp. A
Andrena sp. C
Andrena sp. D
Calliopsis coloradensis
Calliopsis rozeni
Perdita aperta
Perdita ignota ignota
Perdita lepachidis
Perdita opuntiae
Protandrena (Heterosarus) n. sp. 1
Protandrena albitarsis
Protandrena n. sp. aff. sublevis
Protandrena n. sp. aff. leucoptera
Protandrena n. sp. aff. rudbeckiae
Protandrena n. sp. aff. subglaber
Protandrena neomexicana
Protandrena renimaculata?
Protandrena towsendi

Table 1. Native Bee and Wasp Fauna of Guadalupe Mountains National Park

sented by bumble bees, some sweat bees, and the exotic honey bee—are a minor component. Other bees are cleptoparasites—bees that locate the nests of other bees, usually specific genera, and enter the nest while the host is out and lay an egg in the cell. These are not true parasites in the sense that they do not consume the host, rather they destroy the egg or young larva and then consume the provisions designed for the host. Solitary bees are expected to comprise the majority of the park's bees as they do in other faunas.

A second factor that affects diversity is diverse nesting sites. Although the nesting biologies of most of Guadalupe's residents remain unknown, based on known patterns for the North American fauna the majority will be found to nest in the ground. Arid lands prove to be preferred nesting habitat for many ground-nesting bees (Cane 1991). These nests are frequently inconspicuous. Often the only indication is a small diameter hole in the ground. But if you arrive during the active phase of nesting, you may find little volcanoes of soil, or a mud turret that has been created by the

Family Megachilidae

Anthidium maculosum
Ashmeadiella aff. dimalla
Ashmeadiella bucconis
Ashmeadiella cactorum
Ashmeadiella erema
Ashmeadiella gilletei
Ashmeadiella meliloti
Ashmeadiella n. sp. aff. micheneri
Ashmeadiella prosopidis
Ashmeadiella rubrella
Atoposmia daleae
Atoposmia n. sp.
Coelioxys hirsutissima
Coelioxys mitchelli
Coelioxys rufitarsis
Coelioxys texana
Dioxys productus
Heriades gracilior
Heriades micropthalma
Hoplitis grinnelli
Hoplitis producta
Lithurge apicalis
Megachile (Phaeosarus) n. sp.?
Megachile comata
Megachile inimica sayi
Megachile parallela
Megachile policaris
Megachile spinotulata
Megachile subanograe
Megachile sublaurita?
Megachile texana
Osmia (Acanth.) aff. watsoni
Osmia (Acanth.) n. sp. aff. enixa
Osmia cordata
Osmia gaudiosa
Osmia latisulcata
Osmia lignaria
Osmia prunorum
Osmia ribifloris
Osmia subfasciata
Stelis (Stelidina) n. sp.

Family Apiadae

Anthrophora affabilis
Anthrophora californica
Anthrophora lesquerellae
Anthrophora montana
Anthrophora n. sp. aff. californica
Anthrophora petrophila
Anthrophora sp. porterae gr.
Anthrophora squammulosa
Apis mellifera
Ceratina aff. acantha
Ceratina aff. apacheorum
Ceratina nanula
Ceratina neomexicana
Diadasia australis
Diadasia diminuata
Diadasia sphaeralcearum
Doeringiella sp. 1
Doeringiella sp. 2
Doeringiella sp. 3
Epeolus compactus
Habropoda salviarum
Melecta pacifica fulvida
Melissodes confuse?
Melissodes coreopsis
Melissodes montana
Melissodes sp. 1
Melissodes sp. 2
Melissodes tristis
Nomada (Nomada) sp. A
Nomada (Nomada) sp. B
Nomada (Nomada) sp. C
Nomada n. sp.? aff. zebrata
Nomada sophiarum
Syastra sabinensis laterufa
Syntrichalonia exquisita
Tetraloniella sp. 1
Tetraloniella sp. 2
Xeromelecta californica
Xylocopa californica arizonensis

bee as part of the architecture of the nest. In some instances these turrets are built up and then run along the ground, reminiscent of an entrance to an igloo. Below ground nest architecture is even more varied. All nests have two basic elements: (1) a tunnel, often branched, going down into the ground at the end of which or along which are; (2) cells, oblong pockets in the soil, sometimes lined, in which a mass provision of pollen, usually mixed with nectar is placed, an egg laid, and the cell sealed off. The nest architecture is usually distinctive, at least at the generic level. In some, individual cells are constructed on laterals off of the main tunnel; in others, there is a vaulted chamber with vertical cells in its floor. Cells may be in series or they may be solitary. Most ground-nesting bees nest shallowly. In sandy substrates, however, they may go to extraordinary depths. The deepest recorded nest in North America reached a depth of almost three meters (Parker and Griswold 1982). The preponderance of shallow nesters has management implications. Mechanical impacts, whether they are vehicular or pedestrian, could have a significant impact on populations that nest shallowly, both by interrupting nesting activity and by destroying completed nests.

Ground nesting is the most common nesting strategy but is certainly not the only one. A number of bees nest in cavities either existing or created by the female. Some bees, carpenter bees included, drill into yucca stalks or other pithy stems. Some nest in wood, in old beetle burrows. Other cavities used include snail shells and emergence holes in galls. A variety of materials are used in cell construction by these cavity nesters: leaf pieces, masticated leaves, plant fibers, resin, mud, gravel, and glandular secretions. A few bees, including most resin bees, build exposed nests. Such a nest constructed by an unknown species of *Dianthidium* was found on a stem of a creosote bush (*Larrea tridentata*) in the park. The nest consists of a cluster of cells formed of resin with pebbles adhered across the entire exterior.

A third factor in diversity is specialization in larval diet. While some bees, such as the exotic honey bee, are catholic in their taste, most native bees are much more limited in the scope of their floral visitation. Specialization is typically for pollen, not nectar. Bees may collect nectar from a variety of floral sources for their own energy needs, but the larval pollen diet is often quite specific, often at the level of plant genera (Linsley 1958, Wcislo and Cane 1996). Pollen specialization may lead to restricted temporal activity tied to pollen presentation. Most bees are active during the hottest time of the day from midmorning to midafternoon, but some such as *Andrena* (*Onagandrena*) will only be found at dawn when the flowers of evening primrose (*Oenothera*) are open. Flight times for *Perdita* that specialize on blazing stars (*Mentzelia*) are timed to coincide with their late afternoon flowering. Some evening primrose open at dusk and specialist *Sphecodogastra* can be observed waiting for the flowers to open and even forcing their way in as the bud unfolds.

Commonly, a large suite of both specialists and generalists visit a given flowering plant. One-to-one correspondence of pollinator with plant is rare. Data on bee plant relationships in the park are largely lacking, but specialists have been recorded for creosote bush (*Larrea*), cactus (*Opuntia*), and globe mallow (*Sphaeralcea*), and specialists can be expected on a wide variety of other plants including evening primrose (*Oenothera* and *Cammisonia*), mint (*Salvia*), beardstongue (*Penstemon*), and various composites.

The fourth factor to diversity is phenology. Most bees appear as ephemerals on the landscape in the same way that splashy shows of annuals occasionally grace the desert with their transient beauty. Adult bees of many species are active for at most two to four weeks, during which the female actively nests. After provisioning a cell with pollen and nectar, the female lays an egg then seals the cell. The egg hatches shortly thereafter and a succession of larval instars feed on the provision. A period of dormancy follows completion of the provision. After pupation, the adult emerges, to repeat the cycle. In many bees this is an annual cycle, but some bees have multiple generations within a year. Many bees are strongly seasonal, linked with their floral hosts. This strong seasonality, coupled with a short adult life span, results in a rapid turnover of the fauna. This is evidenced in the three samples from the park. Despite the relatively large number of species in each sample, there is very little overlap between months (Figure 1).

The final factor that can affect bee diversity is faunal affinities, a reflection of historical influences on the bee fauna from diverse source areas. We would expect an enriched fauna for Guadalupe Mountain National Park, lying as it does at the juncture of two biomes, the Rocky Mountains and the Chihuahan Desert. The North American deserts are considered one of the richest areas for bees in the world (Michener 1979). A strong representation of hot-desert-restricted bees is evident here. Over half of the presently known fauna are from the Southwest. So far we lack similar evidence for a northern, montane element. I suspect this is an artifact of our collect-

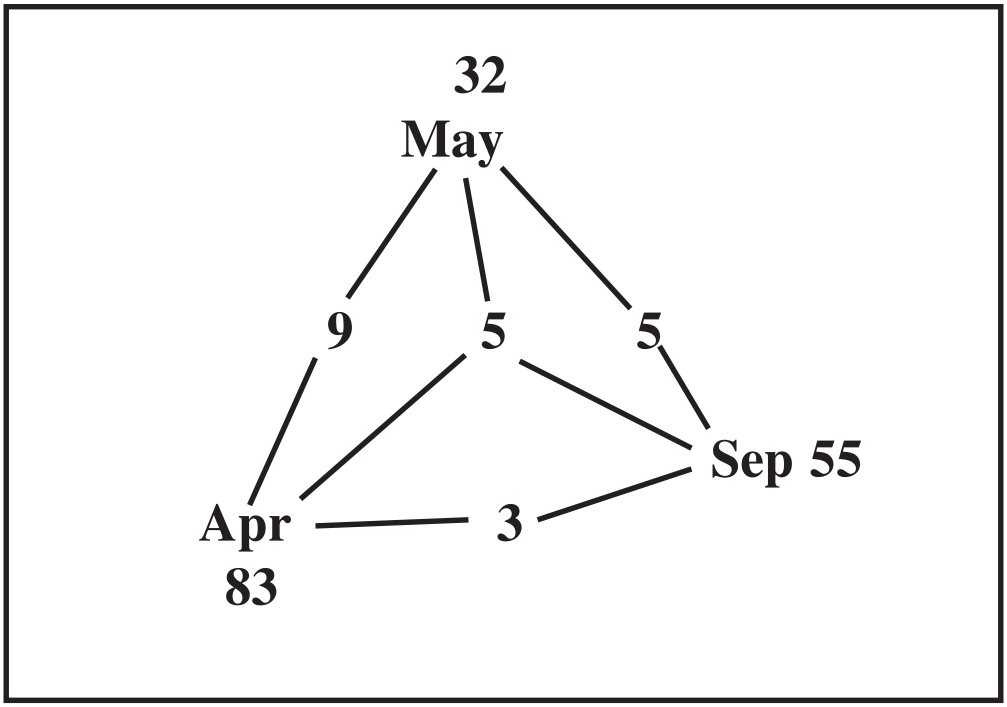

Figure 1. Seasonal turnover in the bee fauna of Guadalupe Mountains National Park. Number of species recorded for each month and numbers in common between months.

ing effort; almost all of our collecting has been at lower elevations. This probably explains why we have not picked up such largely montane groups as bumble bees (*Bombus*). Other bees of the Guadalupes are more wide ranging. Nearly a fourth are widespread in the West, a further eighth are transcontinental. A few Great Plains species are present. A couple of Eastern bees appear to reach their western limit here in the Guadalupes. And *Dufourea boharti* is a representative of an austral element little documented in the United States. There are other hints of this southern influence. One of the new species discovered belongs to the genus *Atoposmia*. Known United States representatives of *Atoposmia* have all been active only in the spring, while those of Mexico are all fall flyers. This new species was found in the fall.

It is likely that there is also an endemic component. This is much more difficult to determine because of the limited collecting in the region. Systematic sampling both inside the park and in surrounding areas is needed to answer this question.

I would predict that a full census of the park will demonstrate a wealth of bee diversity well in excess of 350 species. That prediction is based first on the spatial and phenological limitations of our sampling effort thus far. We have only sampled at three limited times during the year. Due to the strong seasonality of most bees, sampling at other periods of the year should add a significant number of species.

Spatially, our sampling is not representative of the diversity of habitats in the park. Samples are limited to roads and lower stretches of the trails along the southeast side of the park. No collections have been made on the west or in the bulk of the highlands. We have not sampled in burned areas. Work in Pinnacles National Monument (Messinger and Griswold, unpublished data) suggests that bees are diverse in burned areas, perhaps both because there is increased diversity of flora, at least in some situations, and because nest sites are made available. Dunes remain unsampled. Elsewhere, dune systems have been found to be very rich reservoirs for bees, with some species restricted to this substrate (Griswold, et al., 1998). Whether this is true for gypsum dunes is unknown since all the dunes studied thus far have been siliceous.

A systematic multi-year sampling in the park and surrounding areas of all habitats across the entire flowering season would provide the only comprehensive bee study for both the southern Rocky Mountains and the Chihuahuan Desert and would provide valuable data for comparing bee diversity patterns across North America. Such a study would determine the extent of the endemic component and the importance of the park in bee conservation. Study of the gypsum dunes would be of particular value in determining whether they, like siliceous dunes, are repositories of unique faunas. Systematic sampling on all flowering plants would address the importance of floral specialization in bee-plant interactions in the park.

Why survey for bees? Bees can be indicators of the importance of habitats not flagged by more obvious components of the biota. They are part of that "uncharismatic microfauna," as a friend of mine calls it, that shows richness in places like sand dunes, where there are no glamorous vertebrates to speak to their importance. Secondly, bees are vital in the maintenance of floral diversity, a function which may be in jeopardy (Buchmann and Nabhan1996). Two thirds of flowering plants require pollinators. These services are most commonly provided by bees. This includes many rare plants. Studies of the pollination and reproductive biology of 35 rare plants, most of them federally listed, have shown that most, including the local endemic McKittrick pennyroyal (*Hedeoma apiculatum*), require pollinators to vector their pollen (Tepedino, personal communication).

Beyond these considerations, perhaps biodiversity is wonderful in its own right. To know that when you walk along one of the trails in the Guadalupes or just wander across the desert, you will meet 20 to 40 kinds of bees, even if you are unable to call them by name, is to know a bit more about the incredible wealth of life that is our heritage.

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Chapter 14

An Update on the Status of the Rare Plants in Guadalupe Mountains National Park

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Introduction: the history of rare plant classification in Texas and the rest of the world

In Texas the delineation of rare plants formally began in the 1970s with the inception of the Texas Organization for Endangered Species (TOES) and the Rare Plant Study Center at the University of Texas in Austin. These two organizations produced the first lists of rare Texas plants (Gould 1973; Rare Plant Study Center 1974). By the late 1970s the U.S. Fish and Wildlife Service (USFWS) had also produced the first assemblage of endangered and threatened plants as well as a group of potential candidates (USFWS 1975, 1976). The initiation of the Texas Natural Heritage Program (TxNHP) by The Nature Conservancy (TNC) and the General Land Office in 1983 provided yet another list of rare plants, based on TNC ranking methodology (TxNHP 1984). Heightened awareness has led to increased investigation of these species. Additional locations have been found, threats have been managed for or otherwise alleviated, and in general more information has been acquired about many of these species.

Concurrently there has been much thought given to the concept and types of rarity. Early rare plant lists relied on knowledgeable individuals to identify such species, and were often biased toward species that the specialist liked or knew well. Also the spatial and temporal aspects of rarity were often overlooked. Every species is rare somewhere or at some point in time. For example, an annual species may be quite rare or absent in some seasons. Likewise most species are quite uncommon at the limits of their range. However either type of species may be quite abundant in the proper season or in the main part of its range. Some species are rare in both space and time. Rabinowitz (1981) produced a classic study of rare plants, known as the seven forms of rarity. Using three variables with two character states each (geographic range: wide vs. narrow, habitat specificity: broad vs. restricted, and local population size: somewhere large vs. everywhere small), Rabinowitz constructed a table showing that seven of the eight combinations produced species considered rare. Aside from the application of this model to the British flora (Rabinowitz 1986), it has not been widely used and certainly not in Texas. Two widely used classifications of rarity include those of the International Union for the Conservation of Nature (IUCN) and TNC. The several categories employed by the IUCN rely on subjective criteria and thus are open to interpretation. The global, national, and state rankings developed by TNC are based primarily on number of populations with adjustments for abundance, range size, population trends, level of protection, threats, and fragility. Most of these criteria are tied to numerical values. Thus the knowledgeable individual must quantify rarity through a standardized format. Although the final rank is at the discretion of the author of the ranking form, the rank and form are subject to review by other stakeholders and interested parties.

Current rare plant classification in Texas

By the early 1980s, the Rare Plant Study Center was inactive. The Texas Organization for Endangered Species had thrown out their original rare plant list, and began a nominating process to place plants on the rare list. The U.S. Fish and Wildlife Service dropped their category 2 status and relies instead on other agencies and organizations to provide lists of sensitive species. The Texas Natural Heritage Program, although no longer extant, still functions through the Biological Conservation Database (within the Endangered Resources Branch of the Wildlife Division at Texas Parks and Wildlife) and the Conservation Data Center of the Nature Conservancy of Texas. A state list of rare plants was recently produced by these two groups (Poole and Carr 1997). This list used by the Texas Parks and Wildlife Department (TPWD), the state agency with authority for endangered species in Texas to allocate priorities to the state flora, is based on the TNC ranking system. This latest list of rare plants (Poole and Carr 1997) includes 235 G1 (five or fewer populations on a worldwide basis), G2 (20 or fewer populations worldwide), or G3 (100 or less populations globally) species. A "watch" list of S1 or S2 (five or fewer, or 20 or fewer populations, respectively, on a statewide scale) species is also kept by TPWD (Carr 1995), but little additional information aside from name and county of occurrence has been acquired.

Lists of rare plants for Guadalupe Mountains National Park

There have been several floristic studies in the Guadalupe Mountains National Park (Gehlbach et al. 1969, Burgess and Northington 1981) including three studies of rare and endangered plants (Riskind 1974a, 1974b; Burgess and Northington 1981; Higgins 1989). The Riskind list and supplement (1974a, 1974b) were conservative, being composed primarily of globally rare endemics (or near endemics), and disjuncts or peripherals. Two relatively rare species, *Cirsium turneri* and *Senna (Cassia) orcuttii*, reported by Riskind, were not found by Burgess and Northington, nor have any herbarium specimens been observed. Burgess and Northington (1981) conducted a significant study of the flora of Guadalupe Mountains National Park, and uncovered many more disjuncts, peripherals, endemics, and other species rare to the park. Burgess and Northington produced the most exhaustive list of rare plants of the park. Many of the species included in their list are rare within the boundaries of Guadalupe Mountains National Park, but are common or even abundant outside the park. Higgins (1989) did not compose his own list of rare species for the park, but he did conduct survey work and make listing and management recommendations for the category 2 species reported from the park.

Much has changed in the last 25 years. Of the three federally listed plants reported in the Guadalupe Mountains National Park, one has been delisted, another is proposed for delisting, and the third turned out to be a new species. McKittrick pennyroyal (*Hedeoma apiculatum*) was delisted in 1993 due to discovery of additional populations, thus alleviating of the threat of extinction (USFWS 1993). Lloyd's hedgehog cactus (*Echinocereus lloydii*) was proposed for delisting in 1996 because the species was found to be a hybrid, and thus did not qualify for protection under the Endangered Species Act (USFWS 1996, Powell et al. 1991, Zimmerman 1993). Burgess and Northington (1981) found Sneed pincushion cactus (*Coryphantha* or *Escobaria sneedii* var. *sneedii*) at one location in the park. However when Heil and Brack (1985) found *C. sneedii* in the park, they decided that the cactus was a new variety. When they published the entity later, they described it as a new species, *Escobaria guadalupensis* (Heil and Brack 1986). While the park is on the verge of having no listed species, there is a candidate species (formerly referred to as category 1, that is, Guadalupe Mountains fescue (*Festuca ligulata*). This species was collected in upper McKittrick Canyon in 1952. Even though the species has not been relocated in the park, it probably occurs as a small population (as it does in Big Bend National Park) and will require intensive surveys to relocate. Other species of federal concern in the park are the 12 taxa formerly labeled category 2. At present there is not enough information about these plants to make a listing decision.

Guadalupe Mountains National Park has developed its own list of rare plants (Armstrong 1996). The park has several categories: listed species, federal candidate species, National Park Service sensitive species (the former federal category 2 taxa), other species of concern, historically present species, and species of possible occurrence. Most of the taxa on the list are federally listed, federal candidates, former candidates, or taxa formerly or currently tracked by the TxNHP.

A table comparing the lists of Riskind (1974a, 1974b), Burgess and Northington (1981), and the Guadalupe Mountains National Park (Armstrong 1996), with the categories and ranks assigned by the U.S. Fish and Wildlife Service (USFWS 1993), the Texas Organization for Endangered Species (1993), and The Nature Conservancy (1998), has been prepared (Table 1). Nomenclature is drawn from various sources: Correll and Johnston 1970, Johnston 1990, Hatch et al. 1990, Jones et al. 1997, and Kartesz 1994.

Conclusions

For the most part, there is fairly good concurrence among the lists of USFWS, TOES, Guadalupe Mountains National Park, and the ranked taxa of TNC. The lists of Burgess and Northington, and Riskind are more similar because of their identification of peripherals and disjuncts as rare plants of Guadalupe Mountains National Park. It is somewhat inequitable to compare the lists of Burgess and Northington and Riskind with the others. Burgess and Northington recorded any species that was rare within the boundaries of Guadalupe Mountains National Park, and Riskind concentrated on peripherals. Also both lists are dated. The U.S. Fish and Wildlife Service considers only those taxa rare on a worldwide basis. Although both TOES and TNC have provisions to cover statewide rarity, neither group has acted on it, at least in west Texas. Guadalupe Mountains National Park has taken a more USFWS approach, but still retains some peripheral or disjunct elements.

What types of rarity and which species should be of conservation concern to Guadalupe Mountains National Park? For management purposes, an agency such as the National Park Service may be highly interested in preserving what is rare or unique within the boundaries of various units. However, globally rare species that occur only, or primarily within, a political unit should be given first priority over species of local concern. Certainly any taxa endemic to the park, or with the majority of their range within the park, or ranked G1 or T1, should receive the highest protection and management priority. However, federal regulations may also require other species—such as those federally listed, recently delisted, or candidates—to receive high protection regardless of their global distribution or rank. All first priority taxa should have regularly monitored populations to assess population health and demographic trends. Threats should be assessed and managed or alleviated. This group of plants represents the top rare plant conservation priorities of the park. A second tier of species receiving less attention would be species ranked G2, T2, G3, or T3. Populations of these species should be identified and checked on a regular basis. A third level would be comprised of those plants which are peripheral or disjunct in the Guadalupe Mountains. While these species are not rare globally, they are quite rare on a state level. Guadalupe Mountains National Park has for the most part excluded such taxa from its rare plant list. However, these species are unique within Texas. They may also serve as indicator species of plant communities unique or rare to Texas. Occasional checks for the presence of these species and management of their habitat should be sufficient for their continued survival.

Before such priorities and management tasks can be assigned, preliminary work needs to be done. For example, the exact locations of many of the species need to be verified (i.e., *Festuca ligulata*, *Agave glomeruliflora*, *Scutellaria laevis*). Determining the portion of the species' range within Guadalupe Mountains National Park would help in assigning management and research tasks (i.e., *Chaetopappa hersheyi*, *Aquilegia chaplinei*, *Polygala rimulicola* var. *rimulicola*). Much of the knowledge to allow such prioritization is lacking. The present list of Guadalupe Mountains National Park is an excellent start, but would benefit from an assessment according to rarity (and federal regulatory requirements) and the addition of peripherals and disjuncts.

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Table 1. Comparison of rare plant lists of Guadalupe Mountains National Park with selected organizational and agency classifications of rarity

1(Burgess and Northington 1981; Northington and Burgess 1979)
I–endemic to a relatively limited area in and or around the Guadalupe Mountains
II–widespread in other states, but known in Texas from very few localities, usually known only from the Guadalupe Mountains
III–of distributional interest; includes species with relatively small ranges and those near the limits of their known occurrence in the park
IV–rare within the park, but may be common elsewhere in Texas
V–not seen by Burgess and Northington, but previously recorded for the park

2Riskind 1974a, 1974b

3(U.S. Fish and Wildlife Service (1980, 1983, 1985, 1990, 1993)
LE–federally listed as endangered
PDL–proposed to be delisted
DL–delisted
C1–federal candidate with enough information for listing
C2–federal species of concern
3B–no longer considered a valid taxonomic entity
3C–no longer under federal review for listing

4(Texas Organization for Endangered Species 1993)
I–federally listed endangered species
II–federally listed threatened species
V–watch list species
*–species needing more research

5(Armstrong 1996)
FL–federally listed as endangered
CS–federal candidate or category 1 species
NPSSS–NPS sensitive species (formerly federal category 2)
SOC–species of concern without special status within the mountainous Trans-Pecos region
H-NRR–historically present species with no recent records

6The global ranks are primarily from the Biological Conservation Database of The Nature Conservancy (The Nature Conservancy 1998), with some global and all state ranks being assigned by the author and the Texas Conservation Center of The Nature Conservancy of Texas.
G1 (S1)–less than six occurrences known globally (statewide), critically imperiled (in the state), especially vulnerable to extinction (extirpation from the state)
G2 (S2)–6-20 occurrences known globally (statewide), imperiled and very vulnerable to extinction throughout its range (extirpation throughout the state)
G3 (S3)–21-100 occurrences known globally (statewide), either rare and local globally (statewide) or vulnerable to extinction throughout its range
G4 (S4)–more than 100 occurrences known, apparently secure globally (statewide)
G5 (S5)–demonstrably secure globally (statewide)
GH (SH)–of historical occurrence throughout its global (statewide) range, i.e., not observed in the last 50 years
Q–denotes taxonomic uncertainty
?–indicates that the rank is not certain
T–a subrank indicating the global rank for a subspecific taxon
U–a rank has not been assigned

	B&N[1]	RISK[2]	FWS[3]	TOES[4]	GUMO[5]	TNC[6]
Acacia roemeriana	IV					G5S5
Agave glomeruliflora			C2		NPSSS	G2S2
Aletes filifolius	III		3C			G4S2
Allium geyeri	II	x				G4G5S1
Allium perdulce var. *sperryi*	IV		3C		H-NRR	G4T4S2
Amelanchier utahensis	II	x				G5S1
Andropogon hallii	IV					G4S4
Anthericum torreyi	III(IV?)					G5S3
Aquilegia chrysantha var. *chaplinei*	I	x	3C	V	SOC	G4T1S1
Arceuthobium douglasii	II					G5S1
Argyrochosma limitanea ssp. mexicana	II					G4G5T4
Asclepias tuberosa	III					G5S5
Aster hesperius (=A. lanceolatus ssp. hesperius)	II	x				G5T5?S1
Aster laevis var. *guadalupensis*			C2	V	NPSSS	G5T1QS1
Arbutus xalapensis	II					G5S4
Astragalus albulus	II					G3G4S1
Astragalus gypsodes	I		3C	V	H-NRR	G3S2
Astragalus pictiformis	III					G5S1
Berberis repens	II	x				G5S1
Berlandiera lyrata var. *macrophylla (= B. lyrata)*	III				SOC	G5S5
Bouteloua warnockii	III					G4S2
Brickellia parvula	V?	x				G3?S1
Caesalpinia jamesii	IV					G5S5
Campanula rotundifolia	II					G5S3
Carex eburnea	II	x				G5S1
Carex geophila	II					G5S1
Cassia orcuttii (=Senna orcuttii)		x				G2S2
Castilleja latebracteata (=C. nervata)	IV					G3S2
Celastrus scandens	II	x				G5S1
Centaurea americana	IV					G5S5
Cevallia sinuata	IV					G5S5
Chaetopappa hersheyi	I	x	C2	V	NPSSS	G3S2
Chamaesaracha edwardsiana	IV					G4S3
Choisya dumosa	III	x				G5?S2
Chrysothamnus nauseosus ssp. texensis *(C. nauseosus ssp. bigelovii in part)*	I(V)	x	C2	V	NPSSS	G5T2S1
Chrysothamnus pulchellus	IV					G4G5S4
Chrysothamnus spathulatus	II	x				G3S2
Cirsium turneri		x	3C			G3S3
Cologania pallida	II					G4S1
Corallorhiza striata	III,IV					G5S2
Coreopsis lanceolata	II,III					G5S4
Coryphantha dasyacantha (misidentification of C. strobiliformis)	III					
Coryphantha macromeris	IV					G5S4
Coryphantha scheeri	IV					G4S3
Croton suaveolens				V		G3S3
Cryptantha paysonii	III			V	SOC	G3S1
Cystopteris bulbifera ssp. bulbifera	II,IV	x				G5T5S1
Cystopteris fragilis var. *simulans*	III					G5T4S2
Dalea bicolor var. *argyrea*	IV					G4G5T4S4
Dalea frutescens	IV					G5S5
Dalea scoparia	III					G4S4
Delphinium virescens (=D. carolinianum ssp. virescens)	IV					G5T5S4
Dicranocarpus parviflorus	III					G4S3
Echinocereus lloydii			PDL	I	FL	G2QS2
Epipactis gigantea	IV					G4S3
Epithelantha micromeris	III					G4S3
Equisetum kansanum (= E. laevigatum)	III	x				G5S3
Erigeron rusbyi (=E. arizonicus)	II					G3G4QS1

	B&N$_1$	RISK$_2$	FWS$_3$	TOES$_4$	GUMO$_5$	TNC$_6$
Escobaria guadalupensis *(misidentified as Coryphantha sneedii* var. *sneedii)*	I		C2	V	NPSSS	G1S1
Festuca ligulata	II		C1	V	CS	G1S1
Forestiera pubescens? or neomexicana?	III	x				G5S5
Fragaria bracteata (= F. vesca ssp. bracteata)	II	x				G5T?S1
Gaillardia multiceps	III					G4S1
Galium fendleri	II					G3G4S1
Glyceria striata	II	x				G5S1
Grindelia havardii	III	x				G4S2
Hackelia besseyi (syn. H. grisea)	III,IV	x				G3?S2
Hedeoma apiculatum	I	x	DL	II	SOC	G3S2
Heterotheca viscida	V	x				G3S2
Hexalectris nitida	IV		C2		H-NRR	G3S3
Hexalectris revoluta			C2	V	NPSSS	G1S1
Hymenopappus biennis	V	x		V	SOC	G2S2
Hymenopappus flavescens	IV					G5S5
Hymenoxys richardsonii var. *floribunda*	II	x				G4T4S2
Ipomoea lindheimeri	III					G4S4
Ipomopsis arizonica	III,IV					G3G4S3
Jatropha dioica var. *graminea*	III,IV					G5T5S5
Juniperus deppeana forma sperryi	I	x				G5T1S1
Juniperus scopulorum	(I?)III	x				G5S2
Lactuca graminifolia	II	x				G5?S2
Lathyrus leucanthus (= L. lanszwertii var. *leucanthus)*	II					G4G5S1
Lepidospartum burgessii			C2	V	NPSSS	G2S1
Lesquerella valida	I	x	3C		SOC	G2S1
Lilium philadelphicum var. *andinum*	II	x				G5T?S1
Linum schiedeanum	IV					G4G5S3
Lithospermum multiflorum	III					G4S2
Lithospermum parksii var. *rugulosum*	II-III,IV	x				G3G4T2S2
Lithospermum viride	III					G4S3
Lobelia cardinalis	III	x				G5S4
Lonicera arizonica	II	x				G4S1
Machaeranthera blephariphylla	III					G3?S2
Mammillaria lasiacantha	III					G4S3
Mentzelia humilis	III					G4S2
Monotropa latisquama (= M. hypopithys)	III	x				G5S3
Nama carnosum	III					G4S2
Nama xylopodum	I	x	3C		SOC	G4?S3
Neolloydia intertexta	IV					G4G5S4
Nolina arenicola	III?		C2	V	H-NRR	G2QS2
Oenothera caespitosa ssp. eximia	II	x				G5TUS1
Opuntia schottii	IV					G5S5
Oryzopsis hymenoides	III					G5S3
Ostrya knowltonii	II					G4S2
Panicum ramisetum (= Setaria ramiseta)	IV					G5S5
Penstemon ambiguus	IV					G5S5
Penstemon brevibarbatus	III,IV					G3S3
Penstemon cardinalis ssp. regalis	I	x		V	SOC	G3T2S2
Penstemon dasyphyllus	III					G4S2
Penstemon fendleri	IV					G5S3
Perityle quinqueflora	I				SOC	G3S3
Peteria scoparia	V(IV?)					G4S2
Phanoerophlebia auriculata	III,IV					G4S2
Philadelphus hitchcockianus	II	x				G4S1
Physocarpus monogynus	II	x				G4S1
Physostegia virginiana var. *praemorsa*	IV					G5T4S3
Pinaropappus parvus	I	x			SOC	G3S3
Poa occidentalis	II					G4S1
Polygala rimulicola var. *rimulicola*	I	x	3C		SOC	G2T2S2

1(Burgess and Northington 1981; Northington and Burgess 1979)
I–endemic to a relatively limited area in and or around the Guadalupe Mountains
II–widespread in other states, but known in Texas from very few localities, usually known only from the Guadalupe Mountains
III–of distributional interest; includes species with relatively small ranges and those near the limits of their known occurrence in the park
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II–federally listed threatened species
V–watch list species
*–species needing more research

5(Armstrong 1996)
FL–federally listed as endangered
CS–federal candidate or category 1 species
NPSSS–NPS sensitive species (formerly federal category 2)
SOC–species of concern without special status within the mountainous Trans-Pecos region
H-NRR–historically present species with no recent records

6The global ranks are primarily from the Biological Conservation Database of The Nature Conservancy (The Nature Conservancy 1998), with some global and all state ranks being assigned by the author and the Texas Conservation Center of The Nature Conservancy of Texas.
G1 (S1)–less than six occurrences known globally (statewide), critically imperiled (in the state), especially vulnerable to extinction (extirpation from the state)
G2 (S2)–6-20 occurrences known globally (statewide), imperiled and very vulnerable to extinction throughout its range (extirpation throughout the state)
G3 (S3)–21-100 occurrences known globally (statewide), either rare and local globally (statewide) or vulnerable to extinction throughout its range
G4 (S4)–more than 100 occurrences known, apparently secure globally (statewide)
G5 (S5)–demonstrably secure globally (statewide)
GH (SH)–of historical occurrence throughout its global (statewide) range, i.e., not observed in the last 50 years
Q–denotes taxonomic uncertainty
?–indicates that the rank is not certain
T–a subrank indicating the global rank for a subspecific taxon
U–a rank has not been assigned

	B&N[1]	RISK[2]	FWS[3]	TOES[4]	GUMO[5]	TNC[6]
Polygonatum cobrense	II	x				G4S1
Populus angustifolia				V		G5S2
Populus tremuloides	II,IV					G5S2
Potentilla pensylvanica	II					G5S1
Prosopis pubescens	IV	x				G4G5S3
Prunus murrayana			3C	V*		G2QS2
Pterospora andromeda		x				G5S1
Rafinesquia neomexicana	II					G5?S1
Rhamnus smithii	(IV?)V					G4?S2
Rhus toxicodendron	IV					G5S5
Robinia neomexicana	II	x				G4S2
Rosa stellata ssp. mirifica var. *erlansoniae*	III	x		V	SOC	G4T1S1
Rosa woodsii	III,IV					G5S2
Salvia farinacea	III					G5S5
Salvia summa	I	x			SOC	G3?S2
Scutellaria drummondii	IV					G5S5
Scutellaria laevis			C2	V	NPSSS	G1S1
Selinocarpus lanceolatus	III					G4?S3
Senecio neomexicanus var. *neomexicanus*	II	x				G5T?S1
Senecio douglasii var. *douglasii (syn. S. warnockii)*	I	x	(3B)		SOC	G5T5S5 (G3S3)
Sibara grisea	III?		3C			G3?S1
Sisyrinchium demissum	II	x				G5S1
Smilacina racemosa *(= Maianthemum racemosum ssp. amplexicaule)*	III,IV					G5T2S2
Solanum jamesii	IV	x				G4S2
Solanum leptosepalum (misidentification of S. fendleri)	III					
Sophora gypsophila var. *guadalupensis*	I	x	3C		SOC	G2G3T2S1
Sophora secundiflora	III					G5S5
Stephanomeria wrightii	III	x				G3S2
Stipa curvifolia	I		3C		SOC	G4S1
Streptanthus carinatus	III		3C		SOC	G3S3
Streptanthus sparsiflorus	I	x	C2	V	NPSSS	G2S2
Swertia radiata (= Frasera radiata)	II	x				G4G5S1
Symphoricarpos guadalupensis	I	x	C2	V	NPSSS	GHQSH
Trichostema arizonicum	V					G4S1
Ungnadia speciosa	IV					G5S5
Valeriana arizonica	II	x				G5?S1
Valeriana texana	I	x	3C	V	SOC	G3S2
Verbena macdougalii	II					G5?S1
Viguiera cordifolia	II					G5?S1
Viguiera multiflora (= Heliomeris multiflora var. *multiflora)*	II					G4G5T?S1
Viola guadalupensis				V	NPSSS	G1S1
Viola missouriensis	II					G5?S4
Yucca faxoniana	III,IV					G4S4
Zigadenus elegans	II	x				G5S1

1(Burgess and Northington 1981; Northington and Burgess 1979)
I–endemic to a relatively limited area in and or around the Guadalupe Mountains
II–widespread in other states, but known in Texas from very few localities, usually known only from the Guadalupe Mountains
III–of distributional interest; includes species with relatively small ranges and those near the limits of their known occurrence in the park
IV–rare within the park, but may be common elsewhere in Texas
V–not seen by Burgess and Northington, but previously recorded for the park

2Riskind 1974a, 1974b

3(U.S. Fish and Wildlife Service (1980, 1983, 1985, 1990, 1993)
LE–federally listed as endangered
PDL–proposed to be delisted
DL–delisted
C1–federal candidate with enough information for listing
C2–federal species of concern
3B–no longer considered a valid taxonomic entity
3C–no longer under federal review for listing

4(Texas Organization for Endangered Species 1993)
I–federally listed endangered species
II–federally listed threatened species
V–watch list species
*–species needing more research

5(Armstrong 1996)
FL–federally listed as endangered
CS–federal candidate or category 1 species
NPSSS–NPS sensitive species (formerly federal category 2)
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Chapter 15

Are Small Populations of Columbines More Vulnerable to Inbreeding Depression?

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Introduction

Pattern versus process-based assessment of rarity. Historically, the main criterion for identifying threatened and endangered species has been the scarcity of individuals or populations. Recently, however, scientists have recognized the need to assess rarity and vulnerability based on biological processes in addition to patterns of geographic distribution (Holsinger and Gottlieb 1991). Patterns of populations of reduced distribution, or of a relatively few number of individuals, could be the result of and are potentially affected by two important processes. One process involves the performance of individuals derived from the mating of two related individuals, i.e., inbreeding (Roff 1997), the probability of which increases as population size decreases. A possible consequence is inbreeding depression, a decline in the value of a trait such as fitness (Barrett and Kohn 1991, Hedrick and Miller 1992, Milligan et al. 1994, Ritland 1996b). In addition to the process of inbreeding depression, a second process affecting population fitness is the long-term evolutionary response of populations to natural selection, quantified either by heritability or additive genetic variance of phenotypic traits (Ridley 1993). Collectively, increased inbreeding depression and reduced heritability, both conditions that indicate increased vulnerability and influence rarity, are expected in small relative to large populations; this expectation is the fundamental basis of conservation biology.

Classic estimates of inbreeding depression and heritability. Quantitative trait heritability and the degree of inbreeding depression are classically estimated from phenotypic covariances between individuals of known relatedness or from known pedigrees usually manipulated by controlled crosses in the laboratory or greenhouse (Falconer 1989, Riska et al. 1989). Although these methods are useful for estimating the degree of inbreeding depression and for estimating heritabilities, quantitative traits are highly dependent upon the environment for their expression. Consequently, traditional methods are restrictive in that the estimates of inbreeding depression and heritability obtained under artificial environmental conditions or under manipulative matings may not reflect the natural situation in the field (Lande and Arnold 1983). Field-based measurements from individuals in situ would be especially useful because estimates would not be subject to the same limitations. However, doing so requires an innovative technique to estimate relatedness. We propose to utilize molecular marker data to estimate relatedness between pairs of individuals within a native population. Together, with phenotypic data, this will allow us to estimate levels of heritability and inbreeding depression of quantitative traits phenotypically expressed in their native environment.

Specific objectives to assess processes. Ritland (1996a, 1996c), Ritland and Ritland (1996), and Lynch and Ritland (1998) have developed mathematical and statistical models to estimate relatedness, subsequently yielding field-based estimates of the components of genetic variation for complex traits that determine inbreeding depression and heritability. Phenotypic similarity among pairs of individuals in a given population are due to environmental effects that decline with increasing distance, additive effects of genes, dominant effects of genes, and inbreeding. These causal determinants of phenotypic variation of a particular trait were incorporated into a multiple regression model (Ritland 1996a). Ritland's innovation is that phenotypic similarities and molecular marker data can be obtained for a variety of traits on individuals in their native environment, thereby enabling field-based measurements of inbreeding depression and heritability.

We propose to utilize this model to quantify both the magnitude of inbreeding depression and heritability for a number of morphological, fitness, and life-history traits in populations of *Aquilegia* species, a plant in the Southwest that occurs in small, isolated populations. As a result of comparing estimates of inbreeding depression and heritability across populations of varying size, we will be able to determine, not only the importance of the genetic mechanisms leading to vulnerability of these populations, but also the effect of population size on those processes. Therefore, the system we have chosen to study is an ideal system in which to make associations between inbreeding depression, heritability, and population size.

***Aquilegia* as a model organism.** The genus *Aquilegia* (Ranunculaceae) is composed of at least 70 north temperate herbaceous perennials (Munz 1946). The habitat associated with many of the Southwest *Aquilegia* includes rocky places in canyons, mostly along streams and dripping cliffs; therefore, the biogeographical range of *Aquilegia* is among montane "islands." *Aquilegia chrysantha* Gray var. *chaplinei* (Standl. Ex Payson) *Lott*, commonly referred to as Chapline's columbine, is currently protected from unauthorized collection under the New Mexico Endangered Plant Species Act. The auspices of this act stipulate maintenance of native plant diversity, and species in eminent danger of becoming extinct in the state of New Mexico are categorized as list 1 species. *Aquilegia chrysantha* var. *chaplinei* is currently in the list 1B category because "the taxon is so rare across its entire range and of such limited distribution and population size that unregulated collection could jeopardize its survival in New Mexico" (Sivinski and Lightfoot 1994). The known, limited distribution of Chapline's columbine is endemic to the Guadalupe Mountains, within Eddy County, New Mexico, and adjacent Texas. Chapline's columbine is also considered a U.S.D.A. Forest Service sensitive species; these are rare plant species which the U.S.D.A. Forest Service considers sensitive to land use practices within national forests. Plant species listed in the state of New Mexico are further categorized by three components of rarity, endangerment, and distribution, and given an R-E-D code. Therefore, based on the R-E-D classification, Chapline's columbine is considered to be endangered in a portion of its range (E-2 status) and rare outside New Mexico (D-2 status) (Sivinski and Lightfoot 1994).

Expansion of prior studies. Previous work on Chapline's columbine includes studies involving the amount of historical gene flow inferred from chloroplast DNA data among populations of *Aquilegia chrysantha* var. *chaplinei*, as well as gathering data on populations of *Aquilegia chrysantha* var. *rydbergii*, and *Aquilegia longissima* (Strand et al. 1996, Strand and Milligan 1996, Milligan 1993). Previous genetic analyses of closely-related southwestern *Aquilegia* suggest limited, among-population gene flow within and among mountain ranges in the Southwest (Hodges and Arnold 1994, Strand et al. 1996, Strand 1997). As a result, the population structure of *Aquilegia* enables comparisons among geographically and genetically isolated populations. Further, principal components analysis (PCA) for several floral traits of southwestern *Aquilegia* implies indistinguishable taxonomic boundaries (unpublished data). This understanding of population isolation and relatively recent divergence of southwestern *Aquilegia*, regardless of historical taxonomic treatment, is fundamental for investigating the interplay of quantitative genetics and population size.

Methods

Phenotypic and life history traits. During the summer of 1997, traits on individual plants were measured. Floral morphological traits included length and width of specialized petals (spurs and laminae) and of sepals for up to three flowers per individual. Vegetative morphological traits included plant height, plant diameter, rosette number and leaf number; petiole, petiolule, and leaflet lengths; and widths for both uppermost and lowermost of the basal leaves. Fitness characteristics included the number of flowers and fruit produced, fruit length and width, and seed number for up to three fruits per individual. The methods of collecting morphological data on each tagged plant were repeated in the summer of 1998 to collect individual life history data. Some studies (e.g., Husband and Schemske 1996) suggest that the deleterious effects of inbreeding depression may not affect perennial plant individuals until later stages of their life history. Therefore, morphological data collected over sequential years will provide life history information that could have a heritable basis.

Environmental conditions. At least two components of environmental similarity between individuals could be attributed to phenotypic resemblance of individuals within a population. One component of environmental similarity could be a function of spatial distribution; individuals that are in close, physical proximity to one another are presumed to share comparable microhabitats and, therefore, will resemble one another. To measure this first component, the spatial location of individuals was accurately mapped. This was accomplished by recording locations of each labeled and sampled individual relative to every other labeled and sampled individual and relative to existing landmarks.

A second component of environmental similarity could be a function of similarity in light availability (Child et aI. 1979). Casual observation of *Aquilegia* individuals and other empirical studies (e.g., Pigliucci and Schlichting 1995, Sultan 1996, VanTienderen and VanHinsberg 1996) suggest that phenotypic plasticity in vegetative characters could be attributed to varying light availability—either directly, via affecting photosynthesis, or indirectly, via affecting transpiration—within a given population. We propose to account for these influences by incorporating estimates of light availability into the model. To obtain environmental data that would suffice as an indirect assessment of the effect of the light environment on plant phenotypes, we wish to quantify similarities in light availability from the view each plant has of the sky. Above each sampled plant, sky and canopy photographs were taken with an Olympus OM camera, a 28 mm, wide-angle lens, and Fuji 400 ASA black-and-white film. A blue filter was used to increase the contrast between foliage and sky. For each photograph, the camera was aligned with true north, and a level was used to ensure the camera was positioned on a horizontal plane. Following film development, a Hewlett Packard Scan Jet IIcx was used to scan each image. The scanned images were manipulated with Micrographix Picture Publisher to enhance the contrast between sky and foliage. Subsequently, each image was analyzed with a computer program written by Milligan (unpublished) to calculate the fraction of open sky per image. Overall, these ecological assessments will complement our spatial distribution data and help expand on our understanding of the environmental influences of phenotypic similarity.

Genetic estimates of relatedness. Assessment of relatedness between pairs of individuals depends on availability of genetic information for each individual. Tissue samples from the labeled individuals were collected for laboratory genetic analyses currently being conducted at New Mexico State University. Nuclear DNA was extracted according to the protocols of Strand and others (1996) and slightly modified from the protocols of Milligan (1997). Previous genetic work has been completed on other *Aquilegia* populations (Strand et al. 1996, Strand and Milligan 1996, Milligan 1993), providing 10, polymorphic, single-gene nuclear markers. Following gene amplification via the polymerase chain reaction (PCR), sequence variation of a single nucleotide can be adequately detected using denaturing gradient gel electrophoresis (DGGE) (Dean and Milligan 1998).

To provide an additional set of loci for estimating relatedness, we have surveyed numbers of inter-simple-sequence repeats (ISSR) within the nuclear genome. These regions are hypervariable in many plant species (e.g., Rus-Kortekaas et al. 1993, Roder et al. 1995, Rongwen et al. 1995, Chase et al. 1996, Kelly and Willis 1998); therefore, microsatellite primers are effective in assessing fine-scale variation (Morgante and Olivieri 1993, Wolfe and Liston in press). We have found that polyacrylamide gel electrophoresis of *Aquilegia* DNA amplified with seven ISSR primers provide considerable variation among individuals. This substantial genetic variation visualized on gel images can be accurately detected with an automatic band-detection program, DNA Graphical User Interface (DNA/GUI, Version 2.0). To date, we have acquired genetic data for one entire *Aquilegia* population; the coupled utilization of single-gene and ISSR markers has yielded roughly 110 polymorphic loci. Upon acquisition of the molecular data, we will estimate relatedness via both codominant (Ritland 1996b, Lynch and Ritland 1998) and dominant (Lynch and Milligan 1994) marker-based methods in order to be able to assess the dependence on population size of quantitative genetic parameters.

Synthesis of fitness data, environmental conditions, and genetic architecture. The specific aims are to combine morphological and life history with environmental and genetic relatedness data in order to ascertain quantitative inheritance according to the mathematical and statistical procedures outlined by Ritland (1996a, 1996c). Ritland's (1996a) general model is a regression-based estimator of heritability, inbreeding depression, and environmental effects based on data regarding phenotypic similarities, genetic relatedness, and environmental comparability between pairs of individuals within a population (Equation 1). Genetic determinants of phenotypic similarity (Z_i) for the ith pair of individuals in a given population are additive effects of genes ($2r_i h^2$), dominant effects of genes [$2r_{2i}(H - h^2)$], and inbreeding ($f_{2i}b^2_f$). Environmental determinants of phenotypic similarity (Z_i) for the ith pair of individuals in a given population decline with increasing distance ($a_e - d_i b_d$) and correlate with degree of canopy cover ($c_i b_c$). The complete model then, with an error term (e_i) and with our additional canopy cover term discussed below, is a multiple regression of the causal elements of phenotypic variation:

(Equation 1)

$$Z_i = a_e - d_i b_d + c_i b_c + 2r_i h^2 + 2r_{2i} (H - h^2) + f_{2i} b^2_f + e_i$$

Phenotypic and life history traits. Phenotypic similarity between members of the ith pair (Z_i) will be based on individual phenotypes obtained for each (Z_{i1} and Z_{i2}):

(Equation 2)

$$Z_i = \frac{(Z_{i1} - Z)(Z_{i2} - Z)}{V}$$

where Z and V represent the population mean and variance, respectively, of a particular trait.

Environmental conditions. Pairwise distances and fraction of open sky determine environmental similarity. Similarity in open sky viewed by each plant will be calculated in an analogous manner:

(Equation 3)

$$c_i = \frac{(C_{i1} - C)(C_{i2} - C)}{V}$$

where C_{i1} and C_{i2} and are the percent sky view for a given pair of individuals and C and V represent the population mean and variance, respectively, of percent sky view.

Genetic estimates of relatedness. Molecular genetic techniques provide commensurate resolution to estimate the distribution and variation of relatedness within populations. These quantitative measures of relationships among pairs of individuals will be subdivided into components (refer to Equation 1) reflecting one (r_i) and two (r_{2i}) shared alleles across all loci and shared levels of inbreeding (f_2) between both members of the i^{th} pair.

Our foremost objective is to ascertain quantitative inheritance for the aforementioned fitness traits potentially affecting *Aquilegia* population persistence. The compiled data can be applied to the multiple regression analysis (Equation 1) to associate life-history and morphological traits affecting fitness with the effects of genetic influences, namely the degree of inbreeding depression (b^2_f) and the magnitude of narrow sense (h^2) and broad sense (H) heritability. Our second objective is to associate both types of environmental influences (b_d and b_c) on phenotypic traits. Our third and ultimate objective is to determine if the degree of heritable fitness is due to the effects of small population size. To achieve this goal, we must have a set of comparable estimates of inbreeding depression and heritability across populations of different sizes.

Quantifying population size. To empirically test the prediction that population size affects inbreeding depression and heritability, our motive was to sample from populations exhibiting a range of numbers of individuals. During 1997, data were collected from *Aquilegia* populations varying in the number of individuals (Table 1). Population size estimates entailed counting the number of adult plants and estimating numbers of seedlings and juveniles. Sample sizes range from 20 to 160 individuals, depending upon the population, totaling 419 individuals for all seven populations. The spread of sizes among the seven sampled populations are within the theoretical framework that has clearly established the expected relationship between population size and population

***Aquilegia* population**	**Estimated population size**
Caballero Canyon, Sacramento Mountains, New Mexico	75
Pine Canyon, Chisos Mountains., Texas	100
Cattail Falls, Chisos Mountains., Texas	200
Dripping Springs, Organ Mountains, New Mexico	235
McKittrick Canyon, Guadalupe Mountains, New Mexico	375
Maple Canyon, Chisos Mountains., Texas	500
Ash Springs, San Andres Mountains, New Mexico	3,000

Table 1. Sampled populations and estimates of population size.

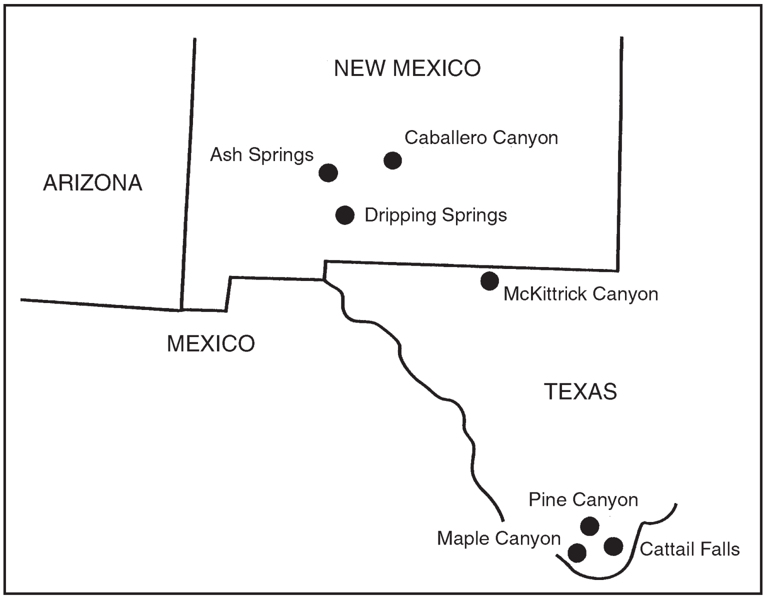

Figure 1. Locations of the seven sampled populations.

performance (Lande 1994, Lande 1995, Lynch et al. 1995). Furthermore, because we are confident of the accuracy in our enumerations of adult, reproductive plants, our knowledge of these counts coupled with data from previous, yet ongoing demographic studies on *Aquilegia* populations (Strand, 1997) translate into a wide range in effective population size (Nunney and Elam 1994, Nunney 1995). Therefore, we hold the potential to assess not only the association of population size with inbreeding depression and heritability estimates, but the association of effective population size with these estimates.

Relationship of quantitative inheritance to population size. Our ultimate goal is the appraisal of whether relatively small populations are characterized by immediate reduction in performance (increased inbreeding depression) and/or a lack of ability to respond to selection (decreased heritability). Because we have selected isolated populations of disparate numbers of individuals, the appropriate statistical analysis is a linear regression of the degrees of inbreeding depression and heritability on population size (Sokal and Rohlf, 1981). These relationships will allow us to determine if quantitative genetic parameters are determined by the number of individuals within populations, as is assumed by many conservation biologists.

Significance to conservation biology. The scientific foundation of conservation genetics has been swayed with evidence of patterns of genetic variability in natural populations and has been influenced by the distribution of neutral, molecular markers to distinguish intraspecific units for preservation. The assumption that genetic variability and diversity as measured at neutral markers shapes the evolutionary fate of taxa remains to be verified (Lynch 1996). Moreover, to understand genetic variation in regard to adaptive differentiation, evolutionary potential, and resistance to selection and threat of extinction, we must concentrate our conservation efforts on understanding the genetic basis of adaptive phenotypes (Hard 1995, Waples 1995). Furthermore, the doctrine of conservation biology builds on certain expectations with respect to relationships—smaller populations associated with an increase in inbreeding depression and a decrease in heritability relative to larger populations—yet the empirical basis of this is not strongly established. Our conservation-oriented study addresses and empirically tests these focal themes of conservation biology and conservation genetics.

The importance of this project ranges from utilization of genetic analyses to provide a powerful tool to clarify the genetic distribution of relatedness within a population, to innovative methods of decomposing phenotypic similarity into classical environmental and genetic components of quantitative genetics. In essence, this study possesses a three-fold significance. First, estimates will be obtained under the environmental conditions encountered by natural populations for a variety of life-history and morphological traits. Second, this nonmanipulative methodology is widely applicable to a variety of taxa. Third, and of utmost significance, this study provides model circumstances in which to investigate whether or not the central tenet of conservation biology—the association of small population size with increased inbreeding depression or decreased heritability—does in fact have an empirical basis in natural plant populations. This knowledge will contribute to our comprehension of the degree to which morphological, fitness, and life-history traits of adaptive importance are heritable and this will, in turn, aid our understanding and implementation of effective conservation strategies.

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Chapter 16

Integrating Genetic Information Into Natural Resource Stewardship

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As stewards of our biological resources, we focus attention on what controls the distribution and abundance of species throughout the landscape. One of the approaches to understanding distribution and abundance is through our long-term monitoring efforts. Typical monitoring for this purpose involves identifying where populations are located and how large they are. Long-term monitoring, by repeatedly obtaining that information, provides a time dimension as well. Such an approach has served us well as a means of inventorying our biological resources. However, this approach is also passive and largely documents changes in abundance or distribution as they unfold through time. Stewardship based on it necessarily remains reactive.

Clearly, the goal for informed natural resource stewardship is that it should involve a proactive strategy, that is, one based on being able to predict future responses to current or anticipated conditions. Rather than merely documenting changes in abundance or distribution, we need to anticipate them and adjust our management plans accordingly in advance. Thus, we must understand the processes involved rather than merely document the patterns.

In the case of anticipating the abundance or distribution of biological resources across the landscape, the processes of prime importance are demographic: growth, survival, reproduction, dispersal, and recolonization. Strategic stewardship must be based on clear understandings and quantification of these processes so that their action can be projected to inform future decisions.

The greatest difficulty faced when trying to understand demography is that often several wildly different processes, with wildly different management implications, can produce similar patterns of abundance or distribution. As a result, monitoring alone cannot distinguish among the possibilities, and therefore, cannot inform management decisions. One of the main points of this paper is to illustrate one case study that integrates genetic and demographic information in a way that successfully distinguishes between competing possible demographic processes. In the process the study illustrates an important role for genetic information in guiding biological resource stewardship.

Aquilegia biology

While focusing attention on the broad importance of proactive stewardship based on explicitly differentiating among competing hypotheses of the demographic processes, which directly influence species distribution and abundance, this paper develops a specific case history involving *Aquilegia* (Ranunculaceae) species in the southwestern United States and adjacent Mexico. *Aquilegia* is an excellent model illustrating many of the important features characteristic of the most endangered resources in this region. For example, the geographic distribution of these plants typifies that of many other plants and animals dispersed throughout the region. These plants require mesic habitats in an otherwise arid landscape and are therefore only found scattered among Springs Canyon, Box Canyon, Dripping Cliffs, and other isolated locations. Furthermore, each local population is generally quite small; typical population sizes range from 20 to 1,000. This is well within the range of sizes subject to genetic problems (Lande 1994a, Lande 1995a, Lynch 1995a, Lynch 1995b) and is not large enough to be immune from stochastic extinction.

Thus, *Aquilegia* populations provide a useful model for understanding how one might obtain information about the demographic properties of biological resources. Our approach to obtaining that information illustrates the need to differentiate between possible biological scenarios with very different demographies. As such it provides insight into how one might proceed in other situations requiring a proactive stewardship strategy based on clear understanding of the underlying demographic processes that determine abundance and distribution of species.

Alternative biological scenarios

From the point of view of understanding, and ideally managing, biological resources distributed among habitat islands, it is important to distinguish between two fundamentally different biological processes responsible for that distribution. First, the populations may be linked by ongoing gene flow and even by periodic recolonization should a local population go extinct. In such a situation, careful management of each individual population may not be required in the long run, because natural recolonization will maintain a set of populations distributed across the landscape. In contrast, the populations may be completely isolated currently, existing only as isolated relicts of a past, more widespread, distribution. In this situation, individual populations may very much warrant specific attention because of the absence of natural recolonization. Indeed, perhaps the most likely outcome in such a case is eventual extinction as each individual population is lost one by one.

The importance of distinguishing between these two situations lies in the implications concerning how one might wish to manage the populations. Unfortunately, information on current location and abundance—the data obtained from typical inventorying activity—cannot distinguish between these two situations. They differ in the processes that have given rise to the current distribution, not in the pattern directly observable by monitoring. Together genetic and demographic data are able to distinguish between the alternatives, though neither alone is sufficient.

The island model. The first scenario—populations interacting in an ongoing manner—has been studied extensively (Wright 1943, Wright 1951, Hartl 1989) since Wright (1931) first formally described it. The fundamental outcome of these studies is that in this situation individual populations achieve equilibrium between loss of genetic variation due to random drift and gain of genetic variation due to introduction from other populations via migration. If the entire suite of populations is considered, equilibrium is between differentiation among populations due to drift in isolation, and homogenization of the populations due to ongoing gene flow or colonization.

Common means of quantifying the degree of differentiation among populations is Wright's F_{st} (Hartl 1989a) which increases with degree of differentiation and N_e m, a measure of effective migration, which decreases with degree of differentiation. With ongoing gene flow or colonization, however, either of these quantities reaches equilibrium and thereafter assumes constant values. The specific equilibrium value (whether $N_e m$ is 0.1 or 0.9, for example) depends on the demography of the populations and the rate of interaction via migration or colonization.

The historical subdivision model. The contrasting scenario—isolated, relictual populations exhibiting no current gene flow or colonization—has also been studied (Slatkin 1995a). In this situation the fundamental outcome is individual populations are initially very similar to

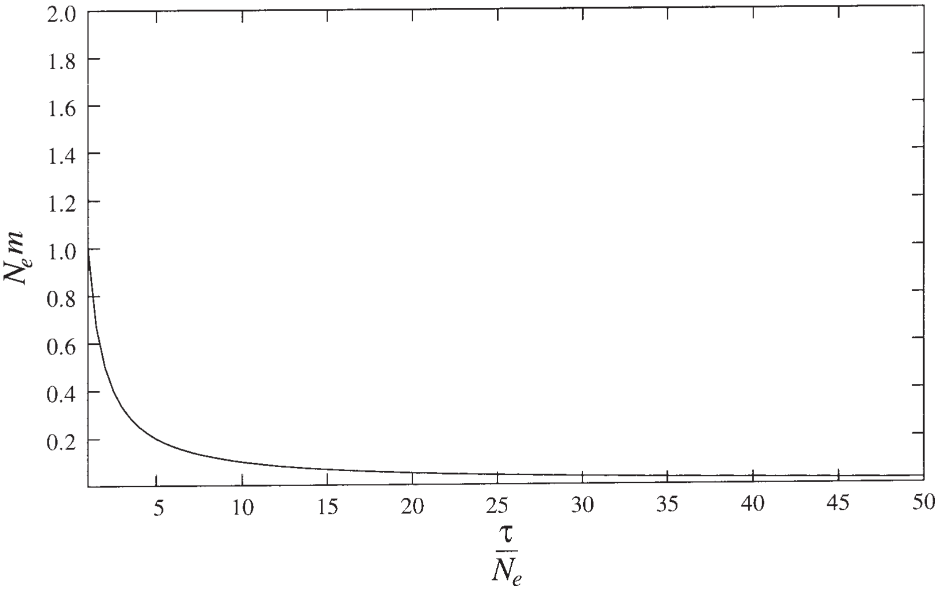

Figure 1. Decay of genetic similarity as a function of time in a set of isolated populations. Time is measured as the number of generations (τ) divided by the effective size of the populations (N_e).

each other immediately following their isolation, yet as time progresses they become increasingly differentiated due to random drift. Eventually all traces of similarity are lost.

The same two quantities—F_{st} which increases and N_e m which decreases—can be used to describe the changing composition of the populations through time. The rate of change depends on the demography of the populations, specifically on the effective population size N_e and on the generation time (Figure 1).

Insufficiency of genetics. Clearly these two biological scenarios make very different predictions about the degree of similarity observable in a set of apparently isolated populations: in one case measures of similarity will remain constant, while in the other they will decay. The difference, however, is entirely in the temporal dynamics, not in the observations available at any single instant in time. Thus, an observation of $N_e m = 0.1$ could be obtained under either scenario, just as could the observation of populations scattered among habitat islands throughout the landscape. Observations of genetic similarity, from which the quantities F_{st} or N_e m are estimated (Nei 1987a), are insufficient alone to distinguish between the two scenarios, just as observations obtained from monitoring are insufficient.

Demography and genetics

If either monitoring or genetic information is insufficient for understanding the processes responsible for a suite of populations limited to habitat islands, the combination of demography and genetics is not. As suggested by Figure 1, given information on the effective size of populations, their generation length, and the amount of time since isolation, one can predict the degree of isolation observed genetically. If the genetic observations do not match those predictions, one can reject the notion that populations are purely relictual. Thus, demographic information provides a crucial means, lacking in purely snapshot monitoring or genetic studies, of investigating the temporal dimension.

***Aquilegia* life cycle.** *Aquilegia* is a long-lived perennial plant. As a result, it exhibits a complex life cycle that must be studied over many years by marking individual plants and following their success. Life cycle diagrams and matrix projection models (Caswell 1989a) are the most appropriate means of organizing such demographic information.

Analysis of this life cycle (Orive 1993, Strand 1997) yields a mean effective size across six populations of 74.1 and a mean generation time of 3.5 years. For *Aquile-*

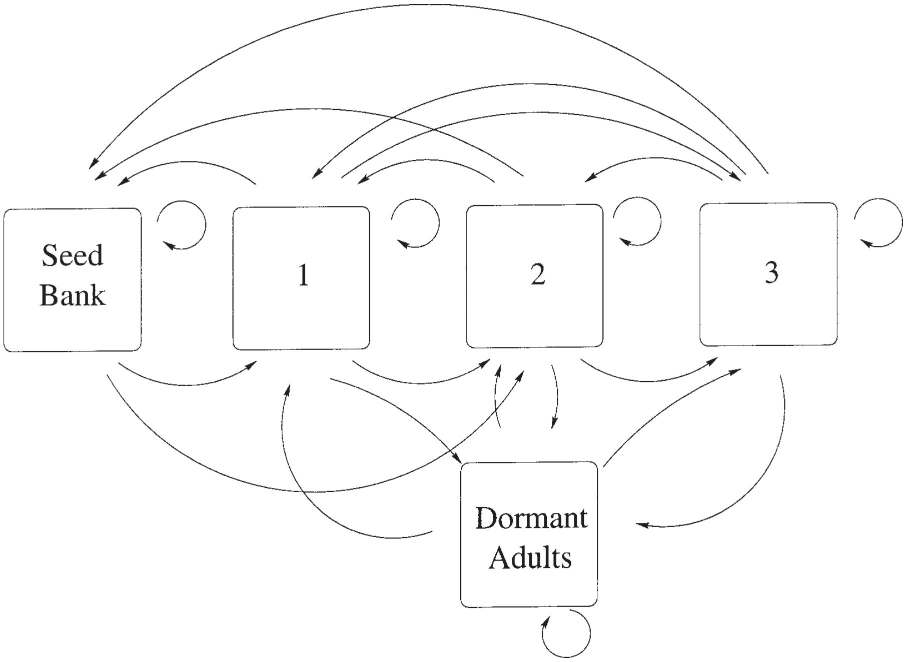

Figure 2. *Aquilegia* life cycle. Stages 1–3 represent progressively larger individuals as determined by the number of leaves produced during the growing season prior to fruiting. Arrows represent transitions, from one stage to another, which are possible during the period of a single year.

gia therefore, the abscissa of Figure 1 reflects values of t / (3.5 • 74.1), where t is the time in years since isolation.

Biogeographical isolation. Although it is highly unlikely that the landscape was ever a continuous expanse of *Aquilegia*, the climatic conditions during the Pleiostocene were much more favorable for *Aquilegia*, and populations were almost certainly more widespread, larger, and interconnected to a much greater degree than they are today. For example, fossil plant debris recovered from packrat middens indicates that a major shift in vegetation occurred between 8,000 and 12,000 years ago (Van Devender and Spaulding 1979, Van Devender 1987). In particular, vegetation typical of cool, high altitude sites dominated low elevation sites prior to that time; afterwards that vegetation was replaced by the dominant desert vegetation present today. The distribution of *Aquilegia* likely followed this same sequence.

Based on this biogeographical evidence, the decay of genetic similarity expected among extant populations of *Aquilegia* corresponds to that illustrated in Figure 1 for $30.9 = t/N_e = 46.2$.

Relict *Aquilegia* populations. Genetic studies of one chloroplast DNA locus (Strand et al. 1996, Strand 1997) and three nuclear loci (Strand 1997) provide measures of genetic similarity of $N_e m = 0.01–0.12$ and $N_e m = 1.67–1.75$, respectively. Together with the time information, this is plotted in Figure 3 as shaded regions indicating the possible ranges of each set of parameters. Evidently the chloroplast DNA data are in agreement with the notion that these are relict populations resulting from long-term isolation, whereas the nuclear DNA data are not.

The differences between the chloroplast and nuclear DNA data reflect the basic differences between dispersal of seeds and pollen. Chloroplast DNA is maternally inherited in *Aquilegia* (Corriveau 1988) and therefore is dispersed only with seeds. The high degree of isolation indicated by the chloroplast DNA reflects the fact that *Aquilegia* populations are not interacting via seed dispersal. Consequently, there is little or no chance of an extinct *Aquilegia* population being recolonized by seed dispersal.

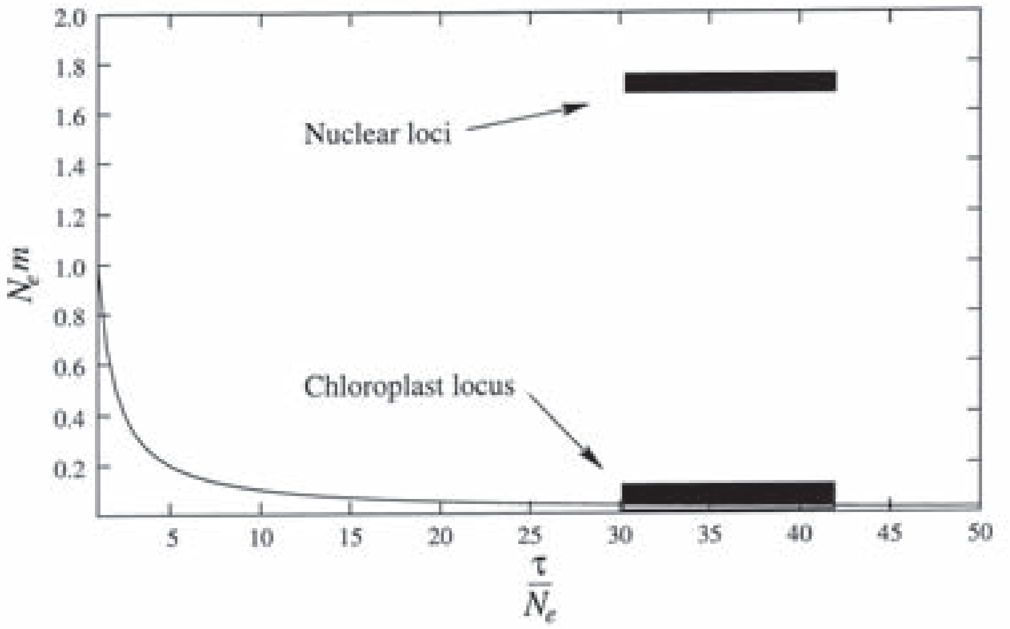

Figure 3. Genetic similarity: chloroplast and nuclear data.

In contrast, nuclear DNA is dispersed by both seeds and pollen. Consequently, the low degree of isolation apparent in the nuclear DNA data reflects the fact that pollen, which is carried by strong flyers such as hummingbirds and hawk moths, is dispersed over much greater distances, at least on the long-term time scales reflected in the genetic data.

Persistence of *Aquilegia* populations

If *Aquilegia* populations in the southwestern United States and adjacent Mexico are isolated relicts—the remainder of more widespread and numerous populations that existed during the Pleistocene—then the current distribution must be a result only of periodic extinction of past populations; once extinct they cannot be recolonized in the absence of seed dispersal. Long-term persistence of *Aquilegia*, therefore, depends entirely on the demographic properties of individual populations and their likelihood of extinction.

Like many riparian plants in southwestern deserts, the performance of *Aquilegia* depends largely on incident rainfall. Figure 4 illustrates the seasonal rainfall patterns adjacent to our demography plots in the Organ Mountains of southern New Mexico. The spring growing season is characterized by highly variable rainfall. Corresponding to that variation in rainfall is also variation in the intrinsic rate of population growth, determined from the projection matrices derived from our demography data (Strand 1997). The relationship between spring precipitation and growth rate based on data for the 1995–1996 and 1996–1997 transitions is ? = 0.0554 x precipitation + 0.3164. This can be used to extrapolate the 12-year precipitation record available for Dripping Springs into a distribution of population growth rate (Figure 5).

This distribution of population growth rates for *Aquilegia* indicates several important points. First, it should be expected that individual populations will do very poorly in some years; ? = 0.33 means that a typical population will decline to one-third its size over a single year and go extinct after only a few years and do very well in others; ? = 1.5 means that a typical population will expand to

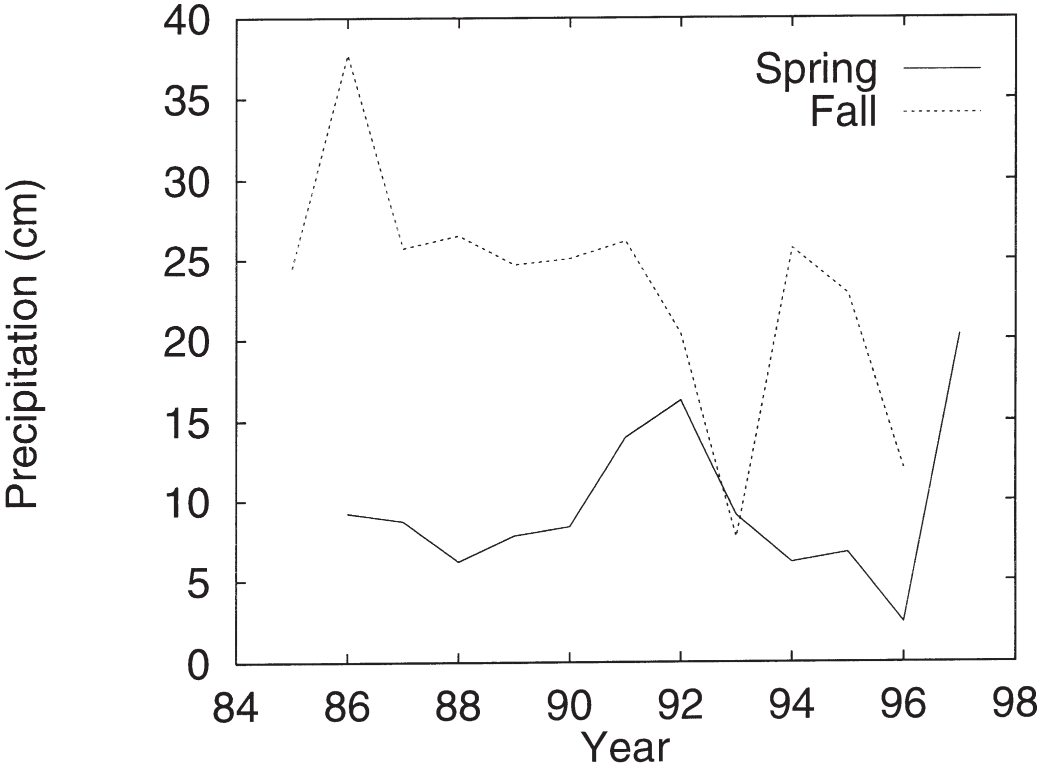

Figure 4. Dripping Springs precipitation record. The spring season represents the period December 16–June 15, while the fall season represents the period June 16–December 15.

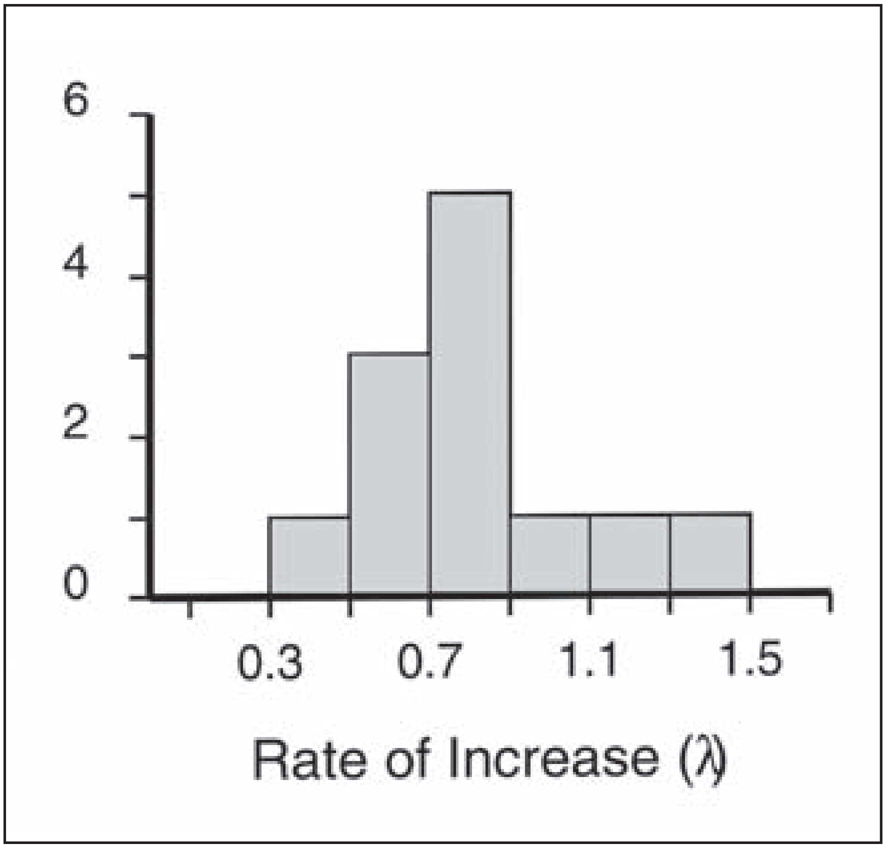

Figure 5: Distribution intrinsic rate of increase. Each value of λ is predicted from the quantity of spring precipitation at Dripping Springs and the relationship between λ and precipitation.

1.5 times its size in a single year. Dramatic fluctuations in performance are to be expected. Conclusions from short-term monitoring may, therefore, be misleading.

More importantly for the issue of long-term persistence, however, is the fact that the mean of the distribution depicted in Figure 5 is 0.8483 (st. dev. = 0.2727). This mean is the long-term growth rate of the population, averaging over annual fluctuations in precipitation, and hence demographic performance. The fact that the mean is less than one indicates that in the long term at least this *Aquilegia* population is likely to decline.

Interplay of genetics and demography

This study clearly illustrates the value of integrating genetic and demographic information to obtain a unified understanding of the processes responsible for the distribution and abundance of *Aquilegia* in the southwestern United States and adjacent Mexico. Basic survey and monitoring activities made it clear that *Aquilegia* existed in small populations scattered about mesic habitat islands in the otherwise arid landscape. However, it provided little more than a snapshot of the current distributional pattern, one of little use for understanding the long-term processes that must inform management decisions. Likewise, genetic data alone could only quantify the apparent degree of similarity among populations, not differentiate between the two major scenarios potentially responsible for the current distribution. Additional demographic and historical information, however, yielded a clear understanding—unattainable from genetic or demographic data alone—of the important ecological processes responsible for shaping the distributional patterns.

As a result of this interplay of genetics and demography, a clearer picture of *Aquilegia* population biology is now available. Clearly populations are restricted to suitable and isolated habitat islands: mesic locations such as springs, box canyons, and dripping cliffs. It is likely, however, that the isolation of these habitat islands translates directly into isolation of populations from the point of view of seed dispersal and recolonization. It is unlikely that should a population go extinct it will be naturally recolonized from another one. Depending on the long-term distribution of precipitation during the growing season, and hence on the long-term population growth rate, it is also likely that individual populations will go extinct. Thus, we may be witnessing the slow elimination of *Aquilegia* from this region.

In contrast, the isolation of the habitat islands does not translate into isolation from an evolutionary point of view. Pollen, and hence nuclear genes, is apparently dispersed among populations. This will tend to reduce genetic problems (e.g., inbreeding depression and loss of heritability) that might be present in these *Aquilegia* populations and in turn reduce the possibility that genetic erosion exacerbates the demographic causes of extinction. Additionally, interaction via pollen dispersal will tend to reduce the possibility of morphological differentiation due to genetic drift. Thus, while pollen dispersal may not enable *Aquilegia* populations to persist in the landscape in the face of periodic local extinction, it can have significant effects on other aspects of the biology of these plants.

Conclusion

While a great deal of attention has been given to this study of *Aquilegia* populations in the southwestern United States and adjacent Mexico, the main point is much broader. Indeed, this study serves primarily to illustrate how we might obtain some critical information needed to act as informed stewards of biological resources. As stewards we can either adopt a reactive response or a proactive strategy. If we focus our attention solely on inventorying and monitoring, that is characterizing the pattern of species distributions as it unfolds over time, of necessity we must be reactive because we lack the understanding of the underlying processes responsible for creating the unfolding patterns. Unless we understand the processes, we cannot predict what the patterns will be in the future, and therefore, cannot adopt a proactive management strategy.

Processes are notoriously difficult to understand, however, because often several (or many) can lead to the same observable pattern. Such was the case with *Aquilegia*. Two extremely different processes with different management implications—one involving the possibility of recolonization of extinct populations and one lacking that possibility—could lead to the same biogeographical pattern and even to the same pattern of genetic similarity. Only the careful quantification of the outcomes of these processes and the deliberate interplay of genetic and demographic information was able to differentiate between these two contrasting biological scenarios. Now, however, we have arrived at a better understanding of the underlying processes and are in a position to make long-term predictions; we are able to adopt a proactive and strategic approach.

Rather than viewing this as a study specifically about the biology of *Aquilegia* in southwestern deserts, regard it as a case study of how one might carefully differentiate among alternative biological scenarios, each with different management implications. Regard it as an illustration of how our understanding can progress from describing the ecological patterns of distribution and abundance to predictive understanding of the processes responsible for those patterns. Regard it as a means of enabling a strategic approach to biological resource stewardship. It is my hope that future studies will follow this lead and directly assess alternative biological processes so that management can be fully informed and as predictive as possible.

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Chapter 17

Mountain Lion Ecology and Population Trends in the Trans-Pecos Region of Texas

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Mountain lions occur in low densities throughout their distribution in the western United States. Small scale radio-telemetry studies provide valuable information on ecology of mountain lions including home ranges, food habits, and densities. Logan and others (1996) studied the dynamics of a population of mountain lions in the Chihuahuan Desert of southern New Mexico, and Harveson and others (1997) provided a review of their ecology in the Trans-Pecos region of west Texas. However, most ecological studies of mountain lions have not provided information on population changes through time.

Previous studies have investigated the use of track counts to index population trends of mountain lions. There is a positive correlation between densities of mountain lions and the number of tracks observed on roads (Van Dyke et al. 1986). Using probability sampling from a helicopter, Van Sickle and Lindzey (1991) estimated densities as a function of number of tracks observed in snow. Smallwood (1994) reported results of a statewide survey of mountain lions in California using track counts. Most recently, Beier and Cunningham (1996) used computer simulations to estimate the statistical power of track counts used by Cunningham and others (1995). Despite the various applications of track counts to index populations of mountain lions, there are no data sets that continuously span more than four years. Beier and Cunningham (1996) reviewed the shortcomings of other methods used to assess changes in densities of mountain lions, such as sightings, depredation rates, and surveys on hunters. Most track surveys rely on implicit assumptions regarding the ability to detect tracks of mountain lions and the quality of the substrate. These assumptions are rarely met consistently throughout a survey route. Scat, scrapes, and kills, as well as tracks, however, are indicators of the presence of mountain lion. The purpose of this paper is to provide data on long-term population trends of mountain lions as indexed by surveys for more than one type of sign.

Material and methods

Data were collected from two national parks within the Chihuahuan Desert ecosystem. Carlsbad Caverns National Park and Guadalupe Mountains National Park were established by in 1930 and 1972 respectively. Carlsbad Caverns National Park is located within Eddy County, southern New Mexico, and encompasses 189 square kilometers. Guadalupe Mountains National Park is located in Culberson and Hudspeth counties of west Texas and is 310 square kilometers. Carlsbad Caverns National Park contains desert shrub and mountain shrub vegetation types (Glass et al. 1974). Typical vegetation on Carlsbad Caverns National Park includes lechuguilla (*Agave lechuguilla*), scrub juniper (*Juniperus pinchotti*), and mountain mahogany (*Cercocarpus breviflorus*). Vegetation types on Guadalupe Mountains National Park are

Carlsbad Caverns National Park		**Guadalupe Mountains National Park**	
Watershed (km increments)	**Length (km)**	**Watershed (km increments)**	**Length (km)**
East Walnut	13	Upper Dog	13
West Walnut	13	Manzanita	11
North Rattlesnake	10	Southwest McKittrick	11
South Rattlesnake	9	Southeast McKittrick	12
East Slaughter	10	Mid McKittrick	14
West Slaughter	10	El Capitan	13
South Slaughter	11		
Total	76	**Total**	74

Table 1. Multiple-sign mountain lion transects surveyed for Carlsbad Caverns National Park and Guadalupe Mountains National Park, fall 1987 to spring 1996.

similar to Carlsbad Caverns National Park but include creosotebush (*Larrea tridentata*) and conifer communities (Glass et al. 1974), and oaks (*Quercus* spp.) and pines (*Pinus* spp.) occur at higher elevations. Average annual precipitation (1986–1995) for Carlsbad Caverns National Park and Guadalupe Mountains National Park is 41.0 centimeters and 45.3 centimeters, respectively (NOAA 1986–1995).

The National Park Service initiated a program monitoring populations of mountain lions (Smith et al. 1988) in fall 1987 at the conclusion of an ecological study of the felids (Smith et al. 1986). On Carlsbad Caverns National Park, 76 kilometers of permanent curvilinear transects were established within park boundaries. Average (± SD) transect length for Carlsbad Caverns National Park was 10.9 (± 1.57) kilometers (Table 1). An additional 74 kilometers of transects were established within Guadalupe Mountains. Average (± SD) transect length for Guadalupe Mountains National Park was 12.3 (± 1.21) kilometers. Transects were distributed along canyons, ridges, and park trails throughout seven watersheds within Carlsbad Caverns National Park and six watersheds in Guadalupe Mountains National Park. Telemetry data (Smith et al. 1986) and other information on mountain lion patterns were used to establish permanent transects (Smith et al. 1988).

Transects were walked each spring (April to May) and fall (October to November) from fall 1987 to spring 1996. Using compass and maps, two to five observers traveled between 8 to 15 kilometers/day along transects. Observers, trained in the identification of sign of mountain lions, recorded the location (km increment), type, and identifying characteristics of sign. Sign was defined as tracks, scat, scrapes, or kills of mountain lions.

Tracks were recorded as mountain lion only if they had characteristic features such as three-lobed heel pads, rounded toes, and width of the heel pad greater than 42 millimeters (Belden 1978, Fjelline and Mansfield 1989). A set of tracks was defined as continuous if the tracks were in the same direction and of similar size (Smallwood 1994) and were only counted once. Scat of mountain lion was distinguished from other carnivores by diameter and shape. Only scat that was segmented, contained mammal hair, and was greater than 29 millimeters in width was recorded (Johnson et al. 1984). Mountain lion frequently scrape to mark their territory (Seidensticker et al. 1973). Only scrapes greater than 15-millimeters wide (Seidensticker et al. 1973) were distinguished as mountain lion. Canine punctures, feeding pattern, and the presence of mountain lion tracks, scrapes, and scat were used to assess whether mountain lion were involved at carcasses along the transects.

Because of inherent problems with independence of sign of mountain lion, we weighted each type equally and reduced the data to a presence-absence format for each kilometer along the transect (Beier and Cunningham 1996). For example, a kilometer segment of transect containing a kill site that contained mountain lion tracks, scat, and scrapes would be assigned a value of one. Data from Carlsbad Caverns National Park and Guadalupe Mountains National Park were analyzed separately. We expressed the amount of sign found (season-year) as the mean number of kilometers within a watershed with sign of mountain lion. We used Chi-square to test for independence of the amount of sign detected and the number of observers.

Data were analyzed for each park by splitting the data in half (location of the missing data). Carlsbad Caverns National Park was separated into fall 1987 to fall 1991 (n = 9) and from spring 1992 to spring 1996 (n = 9). Data were not collected on Guadalupe Mountains National Park for fall 1992, thus data were separated from fall 1987 to fall 1991 (n = 9) and from spring 1992 to spring 1996 (n = 8). We used simple linear regression (Ott 1993) on halves of data from Carlsbad Caverns National Park and Guadalupe Mountains National Park to test for linear trends in sign. We applied Kendall's tau (T) and Spearman's rho test for trends (Conover 1980) to each half of the data for each area.

Results

On Carlsbad Caverns National Park, a cumulative total of 1,368 kilometers of transects were walked by observers from fall 1987 to spring 1996. A total of 115 mountain lion scats, 40 sets of mountain lion tracks, 29 mountain lion scrapes, and 6 mountain lion kills was identified along the transects. The mean (± SD) number of kilometers/watershed with sign for Carlsbad Caverns National Park from fall 1987 to spring 1996 was 1.50 (± 0.53) and was highest in spring 1994 (2.29) and lowest in fall 1991 (0.43). Data were not recorded for all watersheds in Guadalupe Mountains National Park. On Guadalupe Mountains National Park, 1,103 kilometers of transects were walked during the nine-year period. Fifty-three mountain lion scats, 43 mountain lion scrapes, 4 sets of mountain lion tracks, and 3 mountain lion kill were recorded along transects on Guadalupe Mountains National Park. The mean (± SD) number of kilometers/watershed with sign for Guadalupe Mountains National Park from fall 1987 to spring 1996 was 1.10 (± 0.95) and

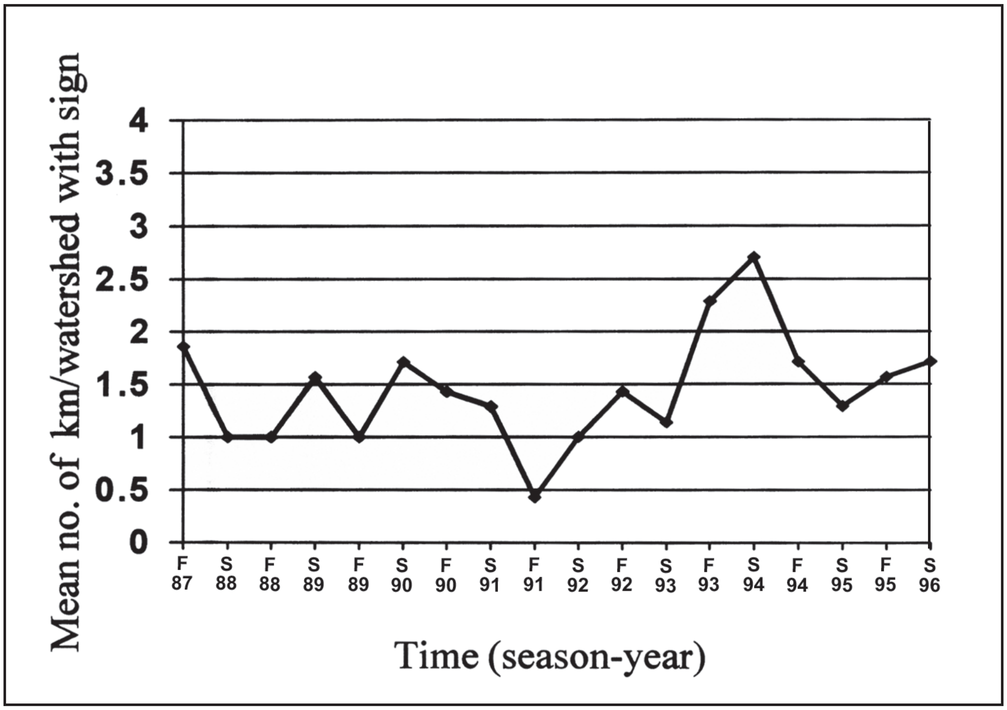

Figure 1. Changes in mean number of kilometers/watershed with mountain lion sign on Carlsbad Caverns National Park from fall 1987 to spring 1996.

ranged from 0.17 (fall 1989, fall 1993) to 3.80 (fall 1987). The type of sign located for the two parks was different (X^2 = 177.65, 3 d.f., $P < 0.001$). For both parks, the amount of sign recorded was independent of the number of observers (X^2 = 0.13, 1 d.f., P = 0.716).

No linear trends were detected (Figure 1) for either the first (F = 1.30; d.f. = 1, 7; R^2 = 0.16, P = 0.29) or second half (F = 0.46; d.f. = 1, 7; R^2 = 0.06, P = 0.52) of the data on Carlsbad Caverns National Park. No trend was detected for Carlsbad Caverns from fall 1987 to fall 1991 (Spearman's R^2 = -0.32, P = 0.40; T = 156, $P > 0.20$) or for Carlsbad Caverns National Park from spring 1992 to spring 1996 (Spearman's R^2 = 0.43, P = 0.25; T = 68.5, $P > 0.20$).

There was a negative trend (Figure 2) using both linear regression (F = 4.38; d.f. = 1, 7; R^2 = 0.38, P = 0.07) and nonparametric tests (Spearman's R^2 = -0.62, P = 0.07; T = 176, $P < 0.05$) for Guadalupe Mountains National Park from fall 1987 to fall 1991. Conversely, there was a positive linear trend using both linear regression (F = 13.91; d.f. = 1, 6; R^2 = 0.70, P = 0.01) and nonparametric tests (Spearman's R^2 = 0.81, P = 0.01; T = 16, $P < 0.05$) for Guadalupe Mountains National Park from spring 1992 to spring 1996.

Discussion

The difference in proportion of sign on the two areas was attributed to the dominant substrates. In Carlsbad Caverns National Park, the transects contain a greater amount of sandy areas on Carlsbad Caverns National Park and tracks of mountain lions were observed there more frequently. By contrast, transects on Guadalupe Mountains National Park are dominated by rocky trails. By definition, an index is a measure comparable only to itself (Davis and Winstead 1980) and therefore comparisons were not made between areas.

Our implicit assumption in this study is that the detection of sign is consistent from year to year. This assumption differs from previous studies (Smallwood 1994, Beier and Cunningham 1996) in that detection does not need to be consistent within the sampling periods (i.e., from transect to transect). The long-term nature of these data minimizes violations to the assumption of detection.

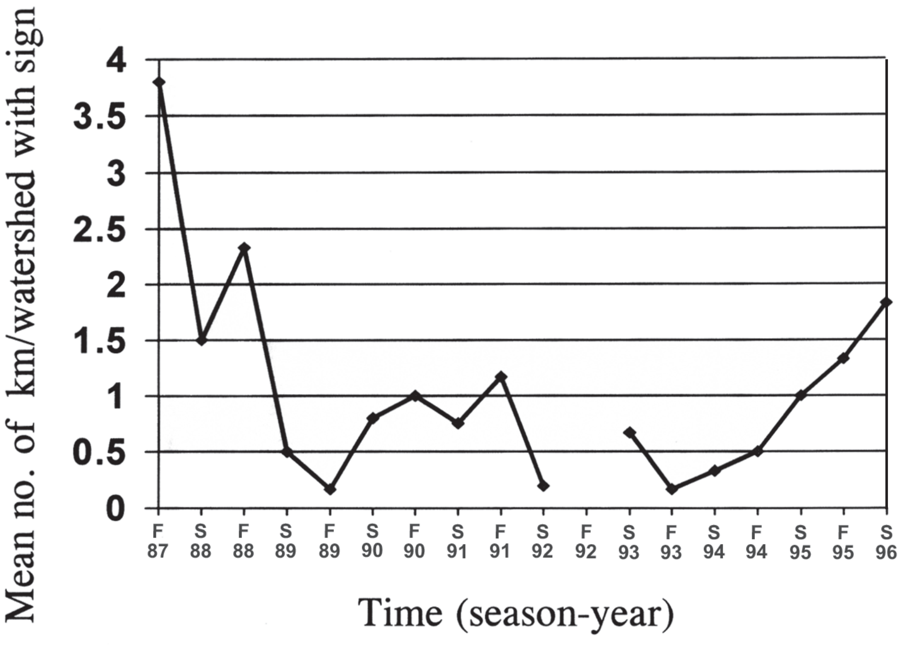

Figure 2. Changes in mean number of kilometers/watershed with mountain lion sign on Guadalupe Mountains National Park from fall 1987 to spring 1996.

The applicability and cost-effectiveness of surveys of multiple signs is greater than surveys of single signs (i.e., tracks). Van Dyke and others (1986) reported an average distance of 80 kilometers between sets of tracks in their evaluation of a roadside count. Van Sickle and Lindzey (1991) required adequate snowfall and a helicopter to monitor populations of mountain lions using track counts in snow. Neither method is realistic for monitoring mountain lion populations in the Southwest. Furthermore, with the incorporation of scat, scrapes, and kills in multiple-sign counts and the reduction of these data to a presence-absence format, the variation between novice observers and experienced trackers is reduced. In addition, the conservative criteria used in this study (Smith et al. 1988) decreases the subjectivity associated with identifying sign of mountain lions.

The decline in numbers on Guadalupe Mountains National Park may be attributed to either precipitation related variables (e.g., declining prey numbers), habitat loss, high mountain lion mortalities, or a combination of factors. Smallwood (1994) attributed changes in mountain lion numbers in California to habitat degradation. Because our study was conducted in national parks, habitats remained unchanged. The primary mountain lion prey on Carlsbad Caverns National Park and Guadalupe Mountains National Park include deer (*Odocoileus* spp.) and collared peccary (*Tayassu tajacu*) (Smith et al. 1986). However, deer and collared peccary populations have remained unchanged during this period (unpublished data). Average annual precipitation during this study varied from 66% to 189% and is considered normal compared to long-term patterns.

A reduction in numbers of mountain lions may have affected our results. Mortalities in the area surrounding Guadalupe Mountains National Park and Carlsbad Caverns National Park are high. From 1982 to 1984, six of eight and four of seven radio-collared mountain lions died as a result of predator control (Smith et al. 1986) on or near Guadalupe Mountains National Park and Carlsbad Caverns National Park, respectively. The Guadalupe Mountains National Park is

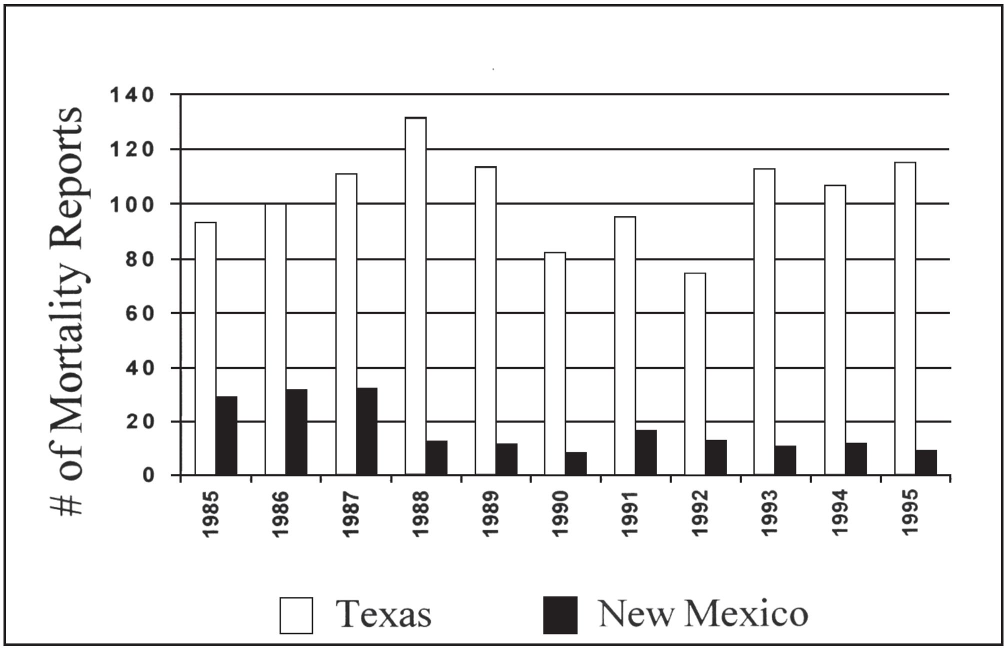

Figure 3. Number of reported mountain lion mortalities in the Trans-Pecos region (7.3 million hectares) of Texas (Russ 1996) and Unit 30 (0.61 million hectares) of southeastern New Mexico, 1985–1995 (Game and Fish Commission, unpublished data).

primarily surrounded by private Texas ranches where the harvest of mountain lions is unrestricted. Russ (1996) reported that the number of annual mortalities from the Trans-Pecos region were consistent and ranged from 70 to 130 individuals from 1986 to 1995 (Figure 3). Although area-specific data are not available, a peak in mountain lion mortalities occurred between 1986 and 1989, which corresponds to a decline in mountain lions we observed during the same period.

Carlsbad Caverns National Park is bordered primarily by private ranches and Lincoln National Forest. Depredation permits are occasionally granted by the New Mexico Department of Game and Fish Commission for the areas surrounding Carlsbad Caverns National Park (see Figure 3). The unregulated harvest of mountain lions in the Trans-Pecos region of Texas and the depredation efforts in southeastern New Mexico appears to have negatively affected their numbers in Carlsbad Caverns National Park and Guadalupe Mountains National Park. Research efforts should focus on validating the indices of mountain lions reported herein with known densities (i.e., radio-telemetry).

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Chapter 18

The Reproductive Biology of McKittrick Pennyroyal, *Hedeoma apiculatum* (Lamiaceae)

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Introduction

Flowering plants may reproduce by apomixis (i.e., vegetatively or by parthenogenesis), by sexual means, or by some combination of the two. For all species, genetic variation in progeny, and the attendant ability of some progeny to successfully respond to changed environmental circumstances, can only be engendered by sexual reproduction. Outcrossing in particular will promote genetically diverse progeny. Thus, the vast majority of angiosperms reproduces sexually either regularly or at some time during their lives and many have evolved self-incompatibility mechanisms to increase their chances of successful outcrossing (Nettancourt 1977).

In this report we will describe the breeding system of a rare mint, *Hedeoma apiculatum*, listed under the Endangered Species Act, which is restricted to the Guadalupe Mountains of Texas and New Mexico (U.S. Fish & Wildlife Service 1985, Anonymous 1988). Members of the mint family (Lamiaceae) are mostly cross-pollinated although some taxa commonly self-pollinate, either automatically or with the assistance of flower visitors (Huck 1992). Indeed, Irving (1980) has reported that some members of the genus *Hedeoma* are commonly self-pollinating. One might predict that sexual reproduction is likely to be especially important for rare plants such as *H. apiculatum* because phenomena such as genetic drift and inbreeding depression tend to genetically impoverish small, fragmented populations (Hamrick and Godt 1996). In particular, we might expect McKittrick pennyroyal to be self-incompatible and obligately outcrossed. However, an alternative hypothesis is also available. Many biologists reason that there is a positive relation between a plant's abundance and its attractiveness to pollinators and as a plant becomes rare it experiences increasing selection for self-compatibility and automatic self-pollination (Levin 1971, Jain 1976). We will examine these competing hypotheses for McKittrick pennyroyal.

Sexual reproduction begins with pollination—the movement of viable pollen grains from dehiscing anthers to a receptive stigma. Pollen may be moved to stigma(s) in the same flower, but more often it is moved to other flowers of the species, either on the same plant or on a different one. Such movement typically requires the cooperation of animals, usually insects, which visit the flowers for nectar and/or pollen and unwittingly serve as agents of pollen transport. A variety of animal taxa affects pollination in the large and diversified mint family (Lamiaceae), including lepidopterans (butterflies and moths), dipterans (flies), hymenopterans (aculeate wasps and, especially, bees) and birds (Huck 1992). Such a variety of visitors to the flowers of a rare plant might be advantageous to successful fruit and seed production. Here, we report on the insect visitors and likely pollinators of *H. apiculatum*.

A recent review suggests that sexual reproduction by flowering plants is frequently limited by inadequate pollination (Burd 1994). Rare plants are especially likely to be ignored by pollinators because of their low numbers

(Levin and Anderson 1970). Thus, although inadequate pollination is unlikely to initiate a common plant's descent into rarity, it may very well hasten a rare plant's descent towards extinction. Thus, we ask whether fruit and/or seed production by *H. apiculatum* gives any indication of being pollinator limited.

Materials and methods

Our studies of the breeding system, and most of the insect collections were conducted on the McKittrick Ridge population in Culberson County, Guadalupe Mountains National Park, Texas. Insect collections were also made over a few days on the Hunter Peak population in Guadalupe Mountains National Park. Geology, soils, habitat, and vegetation associated with McKittrick pennyroyal are described in U.S. Fish and Wildlife Service (1985) and Anonymous (1988).

Breeding system. Thirty-three plants, each with at least five unopened flower buds, were selected for study. One flower per plant was assigned to each of four breeding system treatments: autogamy (A), xenogamy (X), geitonogamy (G), and open-pollinated (O). The additional flower was used to test for stigma receptivity (SR) in flowers whose anthers had not yet dehisced. Treated flowers were permanently marked on the sepals with a distinctive color dot, and with a colored thread tied loosely around the petiole that varied with treatment. Flowers in the A, X, G, and SR treatments were individually bagged from the bud stage through treatment and until seed was counted two to three weeks later. For the X and G treatments, freshly dehiscing anthers from pollen-donor flowers on a plant at least 15 meters away were plucked with forceps on the first day of anthesis and used to hand pollinate flowers whose stigmas had recurved. To minimize impact on reproduction of this rare plant, seeds were counted by cutting mature fruits open while they remained attached to the plant. Data were analyzed using non-parametric statistics including contingency tables with planned comparisons, and Kruskal-Wallis and Mann-Whitney rank sum tests (Conover 1971).

Day vs. night pollination. To compare fruit and seed production of flowers open primarily during night or day, 15 plants were selected and three buds of about the same age on each were chosen and marked. Each plant had one flower in each of three treatments. Buds for the night pollinator treatment were bagged during the day and unbagged at night (1900 to 0700) continuously throughout flowering and until fruit set. Buds for the day pollinator treatment were bagged at night and unbaggged during the day (0700 to1900). Buds for the control treatment were unbagged throughout the comparison. Seeds were counted on the plants as previously described.

Pollinators. Frequent inclement weather prevented systematic collection of pollinators. Instead, insects were observed and collected from *Hedeoma apiculatum* flowers opportunistically over a period of about four weeks in July and August at Wilderness Ridge in McKittrick Canyon in the northeast section of the Park. Insects were also collected from *Hedeoma apiculatum* on Hunter Peak for two days. The insects were pinned, labeled, and identified by comparison with the collection maintained at the U.S. Department of Agriculture ARS Bee Biology and Systematics Laboratory in Logan, Utah.

Treatment	SR	AUT	GEI	XEN	OPE
N	25	33	32	32	33
# fruits produced	2	6	18	24	16
seeds/fruit		1.67	2.44	2.83	2.71
± SD		0.82	1.10	1.17	1.21

Table 1. Number of fruits produced and mean number of seeds/fruit for five breeding system treatments of flowers of *Hedeoma apiculatum*. SR= stigma receptivity, AUT=autogamy, GEI=geitonogamy, XEN=xenogamy, OPE= open-pollinated control, N=sample size.

Results

Breeding system. Flowers of McKittrick pennyroyal follow the protandrous developmental sequence found in other gullet blossoms in the Lamiaceae (Faegri and van der Pijl 1971; Proctor, Yeo, and Lack 1996). Pollen is dehisced from the two functional anthers a few hours after the flowers open. The style does not recurve, and the stigmatic surface does not bifurcate, until late in the second or early in the third day of anthesis. Flowers that cross-pollinated shortly after they opened before either the anthers dehisced or the style had recurved rarely set fruit (Table 1). Pollen adhered poorly to the unbifurcated stigmas of such young flowers as compared to adherence to the sticky stigmas present after bifurcation. Fruit set of flowers receiving this early pollination treatment set significantly fewer fruit than did open-pollinated control flowers on the same plant (?^{2} = 10.9, d.f. = 1, P = 0.001).

Evidence from the experimental pollination treatments showed that *H. apiculatum* flowers must be visited by insects to produce fruits and seeds. There was a significant difference in fruit set among the three experimental breeding system treatments (Table 1) (?^{2} = 22.0, d.f. = 2, P < 0.001). Flowers in the autogamy treatment produced significantly fewer fruits than did those in the xenogamy and geitonogamy treatments ($\chi^2 = 20.0$, d.f. = 1, $P < 0.001$). There was no significant difference between the xenogamy and geitonogamy treatments. For flowers that produced fruit, those in the autogamy treatment produced fewer seeds than those in the xenogamy or geitonogamy treatments (Table 1), but the difference missed significance (Kruskal-Wallis test, P = 0.076). Thus in contrast to many other species of *Hedeoma* (Irving 1980), *H. apiculatum* is not automatically self-pollinating to any great degree: only 18% of the flowers in the autogamy treatment set fruit. The plants are self-compatible but require agents to move pollen between flowers either on the same or different plants.

We found evidence to suggest that fruit set by *H. apiculatum* flowers is limited by inadequate pollen deposition at least sometimes: open-pollinated control flowers produced significantly fewer fruits than did xenogamy flowers (Table 1) ($\chi^2 = 4.8$, $P < 0.05$). There was no difference between control and xenogamy treatments in the number of seeds/fruit for flowers that produced fruit (Mann-Whitney rank sum test, $P > 0.50$).

Day vs. night pollination. Night visitors, presumably hawkmoths, were as effective at pollinating flowers as were day, or combined night and day, visitors (Table 2). There were no significant differences among treatments in the number of flowers setting fruit ($\chi 2 = 0.62$, d.f. = 2, $P > 0.50$). For those flowers that set fruit, there were no significant differences among treatments in the number of seeds/fruit (Kruskal-Wallis test, $P > 0.90$).

Flower visitors. Frequent and prolonged periods of rain made it impossible to follow strict schedules of insect collection and observation. Thus, our information on diurnal and seasonal changes in the flower visitor fauna is incomplete. Nevertheless, we were able to obtain what we think is a representative sample of flower visitors that are potential pollinators. The flowers of McKittrick pennyroyal are visited by a variety of insects including bees, butterflies, moths, flies and beetles but the most abundant and important appear to be butterflies in the genus *Vanessa* (the

Treatment	Day	Night	Control
N	14	14	15
# fruits produced	7	9	9
? seeds/fruit	2.86	2.89	3.11
± SD	1.46	1.36	1.05

Table 2. Number of fruits produced and mean number of seeds/fruit for day, night, and control bagging treatments.

	WR	HP
Halictidae		
Dialictus petrellus (Ckll.)	x	x
Dialictus pruinosiformis (Crfd.)	x	
Dialictus ruidosensis (Ckll.)		x
Dialictus sp. 29	x	x
Dialictus sp. 30	x	
Megachilidae		
Ashmeadiella cactorum (Ckll.)	x	
Ashmeadiella new species	x	
Apidae		
Anthophora montana Cr.	x	
Nymphalidae		
Vanessa sp.	x	x

Table 3. Important flower visitors of *Hedeoma apiculatum* collected at two sites in Guadalupe Mountains National Park, Texas. WR = Wilderness Ridge (7/14–8/6), HP = Hunter Peak (7/28–8/2).

painted lady), hawkmoths (Sphingidae) of unknown identity, and halictid bees in the genus *Dialictus* (Table 3).

Vanessa butterflies were the most abundant insect group seen on the flowers. Their frequent contact with anthers and stigma as they probed the flowers for nectar assures that they are important pollinators. Hawkmoths were seen visiting the flowers on several occasions when night observations were attempted and are likely responsible for nocturnal pollinations. The abundance of dull metallic bees of the genus Dialictus was somewhat surprising because of their small size (5–7 millimeters), short mouthparts, and the depth of the corolla of McKittrick pennyroyal (20 millimeters). Apparently these bees can gain access to the nectar that accumulates at the base of the corolla (sometimes increased and diluted by the frequent rains) by crawling down the tube through the distal, flared part of the corolla. Dialictus females were also frequently seen collecting and depositing pollen as they crawled over the anthers and stigma.

Discussion

We set out to answer three questions about sexual reproduction in the rare mint, McKittrick pennyroyal: (1) Does the breeding system give any indication of selection for self- compatibility or automatic self-pollination? (2) If the flowers of this species require pollination, what are those pollinators? (3) Is there any evidence that the rarity of this species is related to low reproduction caused by insufficient pollinator attention?

In contrast to expectations (Levin and Anderson 1970), we found no compelling evidence that the breeding system of *H. apiculatum* has been influenced by its rarity. While this species is both self-compatible and slightly autogamous, it is less so than many other members of the genus. Indeed, some annual species of *Hedeoma* are even cleistogamous (Irving 1980). McKittrick pennyroyal fits quite well into Irving's (1980) generalizations that larger flowered species exhibit higher levels of outcrossing than smaller flowered species. Thus, McKittrick pennyroyal is yet another example that belies the conventional assertion that rarity in plants engenders traits that make selfing possible and even inevitable (Tepedino 1999). Indeed, the opposite may well be the case.

McKittrick pennyroyal apparently has not gone the expected way towards increased selfing because, despite its global rarity, local populations still attract a variety of insect visitors. Nymphalid butterflies, as well as several species of bees, particularly those in the genus Dialictus, were important at both sites where diurnal pollinators were collected. Nocturnal pollination, likely by hawkmoths, was also an important contributor to fruit and seed production. This diversity of day and night pollinators undoubtedly decreases the likelihood of both complete reproductive failure in any given year, and reproductive failure sustained over a period of years because of the temporary extinction of a particular pollinator at one site. Such "redundancy" of pollinators is important to encourage.

Although *H. apiculatum* was visited frequently by a variety of pollinators, we nonetheless detected evidence for pollinator limitation: there was a significant increase in fruit production of experimentally outcrossed plants compared to open-pollinated controls. There are at least two explanations for this finding. First, although pollinators were frequently sighted visiting the flowers, they may have been inefficient at transferring viable pollen to receptive conspecific stigmas. Based on their movement on and between flowers and plants, we think this explanation unlikely. It is far more likely that fruit set was reduced in open flowers not because of the inefficiency of pollinators but because frequent precipitation forced pollinators to be inactive. This is not the first study to link inclement weather and reproductive diminishment via pollinator inactivity (e. g., McCall and Primack 1987, Bertin and Sholes 1993). Indeed, such microclimatic connections are likely to be far more common than we suspect (Corbet 1990).

We conclude that there is presently little evidence that the pollination system of McKittrick pennyroyal has either influenced, or been influenced by, the rarity of this species. Of course this is not to say that land managers charged with conserving this species should completely ignore the role played by pollinators in its reproduction, only that there may be more pressing threats such those due to sheep grazing, hikers, and climbers on the limestone rock surfaces where this plant is found (U.S. Fish and Wildlife Service 1985).

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Chapter 19

Methods for Estimating Colony Size and Evaluating Long-term Trends of Mexican Free-tailed Bats (*Tadarida brasiliensis mexicana*) Roosting in Carlsbad Cavern, New Mexico

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Introduction

Mexican free-tailed bats roost in colonies that can exceed several million (Altenbach et al. 1979, McCraken 1984, Wilkins 1989). These large colonies usually occupy caves, although bridges and buildings are also used (Wilkins 1989). Investigators have estimated colony size using a variety of methods ranging from gross ocular counts, to video and still photography (Altenbach et al. 1979, Thomas and LaVal 1988). However, few methods have provided a measure of statistical precision. Colony size, roost geography, repeatability of methods, and cost efficiency are all concerns when determining appropriate methods for estimating abundance. Investigators and managers need a variety of procedures from which to choose so that consistent and useable data can be obtained. Herein, we present progress toward developing reflective infrared photography (RIP) as a means of estimating colony size and assessing long-term trends in large colonies of Mexican free-tailed bats.

Background

Carlsbad Caverns National Park hosts a colony of Mexican free-tailed bats that reportedly reached 3 million in the late 1920s (V. Bailey personal communication with V. C. Allison, see Allison 1937). Another estimate of 8.7 million in June 1936 (Allison 1937) was revised down to 3.6 million by D. M. Roemer and W. T. Route (unpublished data). Both Bailey and Allison (Allison 1937) made their estimates from visual approximations and rough calculations of the volume of air filled with bats during the evening exodus. The accuracy and precision of these point estimates cannot be evaluated.

Investigators at Carlsbad Caverns National Park have documented a series of large-scale die-offs and a population decline beginning in 1955 (Ahlstrand 1974). Similar declines were noted throughout the southwestern United States and Mexico. Residues of organochlorine pesticides, primarily DDT and its metabolite DDE, likely contributed to this decline (Clark 1988, Geluso et al. 1976, Geluso et al. 1981). Despite the ban on DDT in the United States in 1972, DDT may still be causing harmful effects to wildlife in the Pecos Valley and the Guadalupe Mountains (Clark and Krynitsky 1983).

Prompted by this decline, Constantine (1967) used ceiling counts to estimate that there were 66,700 bats in the colony in June of 1957. Sixteen years later, in September 1973, Altenbach and others (1979) employed moving and still photography to estimate there were 218,153 bats in the colony. Most recently, Carlsbad Caverns National Park staff used computer counts of video footage taken during the evening exodus to estimate there were 147,418 bats on September 20, 1987 and 142,386 bats on October 1, 1987 (Roth 1987). Each of these estimates was obtained using different methods and at various times of the year. Ocular counts are highly dependent on observer experience. The use of moving and still photography was complex and not easily repeatable (K. Geluso, personal communication). Computer counts of video footage held promise, but as much as 60% of the flight was missed because of poor camera field-of-view and darkness (Roth 1987). None of the investigators provided a measure of precision, and thus, statistical comparisons between years are inappropriate.

To better understand how this colony reacts to disturbance and environmental change, we attempted to develop a monitoring technique that would provide a consistent and statistically robust estimate of abundance both before young were born and again just prior to migration each year. This would provide insights into over-winter survival and emigration as well as over-summer survival and recruitment. Both are critical for developing management strategies. We also wanted a method that was user-friendly, relatively inexpensive, and comparable with data collected elsewhere in the region.

Study area

Carlsbad Caverns National Park is a 46,766 acre (18,926 ha) park situated in the Chihuahuan Desert of southeastern New Mexico. It was first established as a unit of the National Park System in 1923 to protect Carlsbad Cavern, as well as other caves and portions of the surrounding desert. Carlsbad Cavern itself has approximately 30 miles (48 km) of cave passage and is 1,037 feet (316 m) deep. The cave was created by water percolating through an exposed limestone reef that formed along an ancient inland sea during the Permian period some 280 to 250 million years ago. The cavern receives more than 500,000 visitors per year with the highest visitation occurring from June through August when 2,000 to 6,000 visitors walk through the cave each day (National Park Service 1996). The two visitor access points are through a large natural entrance or by an elevator, which goes from the surface to a depth of 750 feet (229 m).

The large natural entrance measures about 21 x 12 meters and is the primary flight route of bats using the cavern. A second, smaller natural entrance (6.4 x 3.4 m) is used to a lesser degree by bats, likely because of its combined small size and steep incline. As far back as the 1950s and up to the 1980s, the roosting site of the Mexican free-tailed bat colony was centered 69 feet (21 m) west of this small natural entrance. Currently, the colony roosts about 722 feet (220 m) east of the small natural entrance. The historic and current roost areas are in a portion of Carlsbad Cavern known as Bat Cave. Bat Cave extends approximately 1,950 feet (594 m) to the northeast from the large natural entrance.

In addition to Mexican free-tailed bats, 12 other species of bats are known to occur in Carlsbad Cavern, but their numbers are small compared to the free-tail colony. A population of about 3,000 cave swallows (*Hirundo fulva*) began using the cave in the mid 1960s for nesting (West 1991).

Methods

During the winter of 1996, 15 permanent photo-points were placed at strategic locations in Bat Cave (Hildreth-Werker et al. unpublished data). Each photo-point consists of a stainless-steel receiving-pin drilled and fastened with epoxy to bedrock. A stainless steel monorod with camera mount and flash mount (patent pending) provided fast and precise photographs at each point. For complete overlap of photographs, two additional photo points were installed during the winter of 1997, bringing the total to 17. In addition, an articulating monorod was developed and used in 1997, enabling angled photographs for bats roosting low on cave walls.

Photographs were taken with a Nikon FM2 camera and a Nikon 28mm fixed-focal point lens (mention of product name does not constitute endorsement). We mounted an infrared flash unit (Sunpack 622 with TriPak II batteries) along side of the camera to illuminate the cave ceiling. Kodak HIE black-and-white infrared film was exposed by remote control with F-stop set at 5.6, focus set on the infrared setting for infinity, and the shutter left open while one to 10 flashes were fired depending on ceiling height. Negatives were processed and enlarged to 11-by-14-inch, black-and-white paper prints. The negatives were scanned and the resulting digital images placed onto CD-ROM for archival, digital enhancement, and future evaluation with GIS technology.

Gridded transparencies were developed to correspond to the ceiling at each of the permanent photo-points. Grid cell size was calculated from the average ceiling height at each point. Average ceiling height was estimated when bats were not present by raising a helium-filled balloon at three arbitrarily selected locations within the area encompassed by each photograph.

Complete sets of photographs were taken each day for five consecutive days in spring and fall 1996 and 1997. Gridded transparencies were overlaid onto the 11-by-14-inch photographs and grid cells containing bats were counted independently by three observers. Counts by observers were averaged over each five day session to provide an estimate of the area of ceiling covered with bats.

Roosting density can be highly variable depending on factors such as bat physiology and cave temperature. To estimate abundance we multiplied roost area by 200 bats/square feet (2,153 bats/m^2), a conservative estimate of roosting density for Mexican free-tailed bats (Constantine 1967, McCraken 1984, B. Keeley unpublished data). Final estimates were rounded to the nearest 1,000 bats because we considered accuracy beyond that to be impractical. Estimates should be considered conservative. All significance levels and confidence intervals were set at the 0.05 level.

To calculate a minimum population estimate we necessarily made the following assumptions: (1) the entire resident colony, and only the resident colony, was present during the photo sessions

	Daily area estimates (m^2)					Observer summary[a]		
Observer	5/29/96	5/30/96	5/31/96	6/1/96	6/2/96	Avg.	Std.	CV_d
JW	71.35	84.17	77.76	70.61	121.61	85.10	21.14	25
BR	72.37	86.77	78.50	73.11	147.16	91.58	31.59	34
JL	74.88	86.77	79.99	77.11	142.05	92.16	28.24	31
Daily summary[b]								
Avg.	72.87	85.90	78.75	73.61	136.94			
Std.	1.82	1.50	1.14	3.28	13.52			
CV_o	2	2	1	4	10			
Final estimated area calculation =						89.61	26.96	30

a = Observer summary provides a measure of daily variability
b = Daily summary provides a measure of observer variability

Table 1. 1996 spring estimates of ceiling area (m^2) covered with Mexican free-tailed bats in Bat Cave, Carlsbad Caverns National Park, New Mexico.

	Daily area estimates (m^2)					Observer summary[a]		
Observer	8/30/96	8/31/96	9/1/96	9/2/96	9/3/96	Avg.	Std.	CV_d
JW	163.42	155.43	180.04	182.74	157.00	167.73	12.86	8
BR	173.17	156.82	171.03	171.03	145.67	163.55	11.93	7
JL	158.68	157.28	170.20	170.01	140.75	159.38	12.06	8
Daily summary[b]								
Avg.	165.09	156.51	173.76	174.59	147.81			
Std.	7.39	0.97	5.46	7.07	8.34			
CV_o	4	1	3	4	6			
Final estimated area calculation =						163.55	11.47	7

a = Observer summary provides a measure of daily variability
b = Daily summary provides a measure of observer variability

Table 2. 1996 fall estimates of ceiling area (m^2) covered with Mexican free-tailed bats in Bat Cave, Carlsbad Caverns National Park, New Mexico.

	Daily area estimates (m²)					Observer summary[a]		
Observer	5/27/97	5/28/97	5/29/97	5/30/97	5/31/97	Avg.	Std.	CV_d
BR	14.96	38.74	44.41	28.06	58.44	36.92	16.46	45
DR	14.21	37.72	40.97	27.31	56.76	35.40	15.87	45
JW	17.56	39.67	43.11	28.06	57.32	37.14	15.13	41
Daily summary[b]								
Avg.	15.58	38.71	42.83	27.81	57.51			
Std.	1.76	0.98	1.74	0.43	0.85			
CV_o	11	3	4	2	1			
Final estimated area calculation =						36.49	15.81	43
a = Observer summary provides a measure of daily variability b = Daily summary provides a measure of observer variability								

Table 3. 1997 spring estimates of ceiling area (m²) covered with Mexican free-tailed bats in Bat Cave, Carlsbad Caverns National Park, New Mexico.

	Daily area estimates (m²)					Observer summary[a]		
Observer	8/29/97	8/30/97	8/31/97	9/1/97	9/2/97	Avg.	Std.	CV_d
BR	134.24	99.96	101.64	61.59	42.46	87.98	36.19	41
DR	136.57	94.11	106.65	62.24	47.66	89.45	35.44	40
JW	135.92	101.36	105.17	61.69	39.58	88.74	38.09	43
Daily summary[b]								
Avg.	135.58	98.48	104.48	61.84	43.23			
Std.	1.20	3.85	2.58	0.35	4.10			
CV_o	1	4	2	1	9			
Final estimated area calculation =						88.72	36.51	41
a = Observer summary provides a measure of daily variability b = Daily summary provides a measure of observer variability								

Table 4. 1997 fall estimates of ceiling area (m²) covered with Mexican free-tailed bats in Bat Cave, Carlsbad Caverns National Park, New Mexico.

(i.e., the population was closed to immigration and emigration); (2) all bats could be photographed during the photo sessions; (3) our methods did not disturb the colony; (4) measurements of ceiling height were accurate and provided unbiased estimates of ceiling area; (5) grid counts were accurate and the resulting estimates of roost area were unbiased; and (6) the roosting density estimate of 200 bats/ square feet (2,153 bats/ m²) is conservative and remained constant during the photo sessions.

Results

Spring and fall photo sessions occurred in late-May–early-June, and late-August–early-September, respectively. Photography normally began about 9:00 a.m. (time of first photograph) and ended about 11:00 a.m. (time of last photograph). Each five-day session required approximately 15 hours in the cave to set up and photograph the colony and about eight hours in the darkroom to develop and print film. An additional two hours were required for each of three observers to tally ceiling grids filled with bats. Thus a total of 29 hours were expended to complete each five-day photo session. Our methods resulted in minimal disturbance to the colony. Occasionally a bat would fly, but we noticed only minor and short-lived changes in colony noise during sessions.

During both years the colony roosted at the far end of Bat Cave about 220 meters east of the small natural entrance above photo-points 1–4. Ceiling geography varied from vertical walls to gradually sloping ceiling domes. Most bats were found along the uppermost portions of three natural domes and a closed mine shaft where ceiling heights ranged from 78 to 95 feet (24 to 30 m) above the cave floor. Small numbers of bats were found low on the cave walls during fall sessions both years. We were unable to photograph these bats in 1996, but a new camera mount in 1997 allowed angled photography of these areas. On days one and two of the 1997 fall session we took photographs at angles between 15° and 30° to record bats occupying low positions on the cave walls. These bats comprised 11.8% of the total area calculation for the 1997 fall session.

In the spring of 1996, we estimate bats occupied 89.6 square meters (± 23.6 m^2) of cave ceiling (Table 1), but by fall this nearly doubled to 163.5 square meters (± 10.0 m^2) (Table 2). In 1997 bats occupied an estimated 36.5 square meters (± 13.9 m^2) in spring (Table 3) and 88.7 square meters (± 32.0 m^2) by fall (Table 4). Each year the area covered by bats expanded by fall, and each year this expansion was further into Bat Cave.

Day-observer estimates were similar for all sessions as illustrated by the consistently low coefficient of variation ($CV_o < 11\%$, Tables 1–4). Estimates between days were more variable (CV_d 7: 45%), due to increasing trends in area of ceiling covered with bats during the spring of 1996 and 1997 and the decreasing trend in the fall of 1997 (Figure 1, Figure 3, Figure 4). Only the fall of 1996 provided consistent daily estimates (Figure 2).

Using the roosting density of 200 bats/square feet (2,153 bats/ m^2) and the mean area of ceiling covered with bats, we estimate that in the spring of 1996 there were about 193,000 bats (± 51,000) in Bat Cave and by fall this nearly doubled to 353,000 (± 22,000). In the spring of 1997 we estimate there were 79,000 bats (± 30,000) increasing to 191,000 (± 69,000) by fall. However, we believe only the fall 1996 estimate of 350,000 bats was representative of the resident colony. This is because the increasing trends in area estimates both springs and the decreasing trend in the fall of 1997 suggests that the population was not closed to emigration and immigration.

Discussion

We conducted our spring photo sessions at the end of May to limit disturbance to pregnant females, which give birth in mid-June to mid-July. Unfortunately, our spring sessions were probably too early. Daily area estimates for both years generally increased (Figure 2, Figure 4). From our data we could not determine whether this ingress was due to returning residents or merely transients moving through on their way to other caves. Constantine (1967) documented bats banded from Bat Cave in early spring being found over 400 straight-line miles

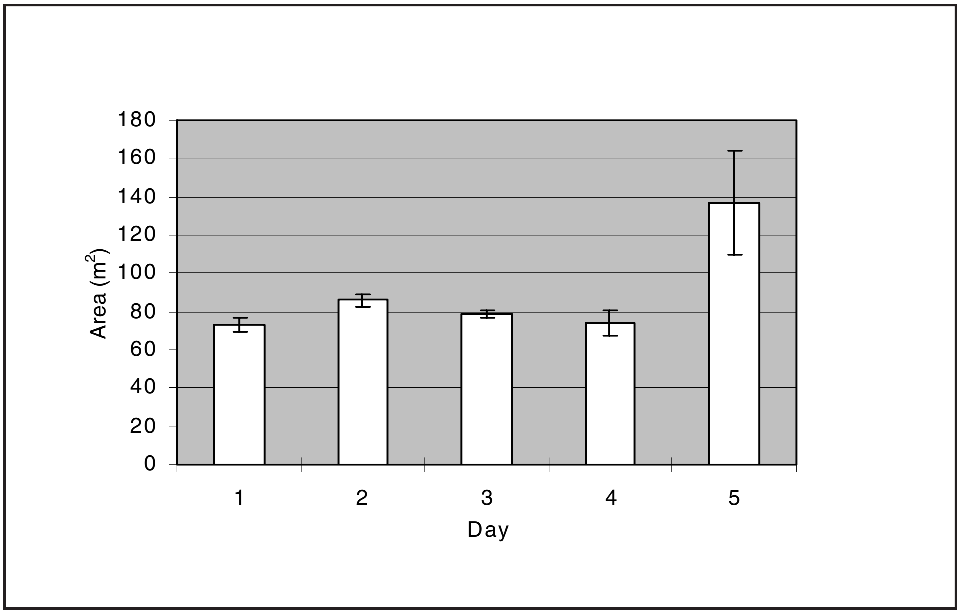

Figure 1. Spring 1996: estimates of roost area. Error bars depict two standard deviations from the mean.

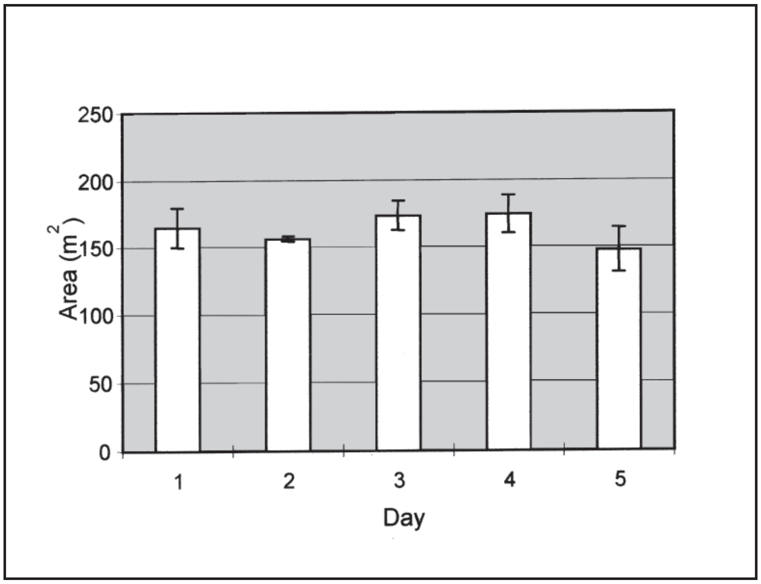

Figure 2. Fall 1996: estimates of roost area. Error bars depict two standard deviations from the mean.

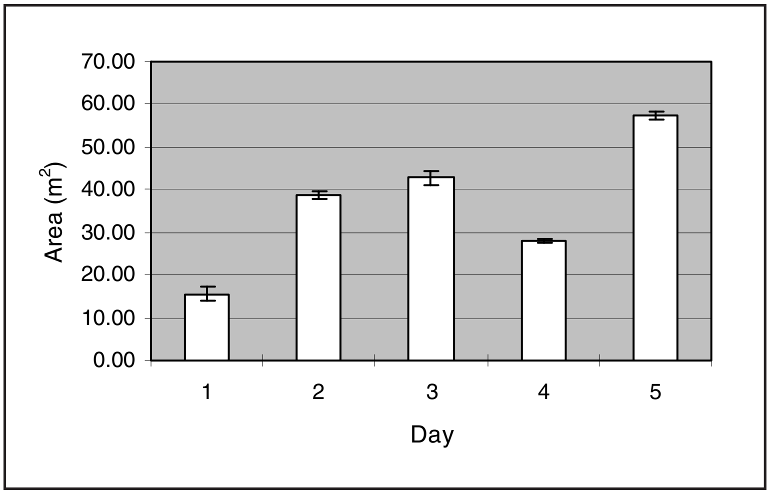

Figure 3. Spring 1997: estimates of roost area. Error bars depict two standard deviations from the mean.

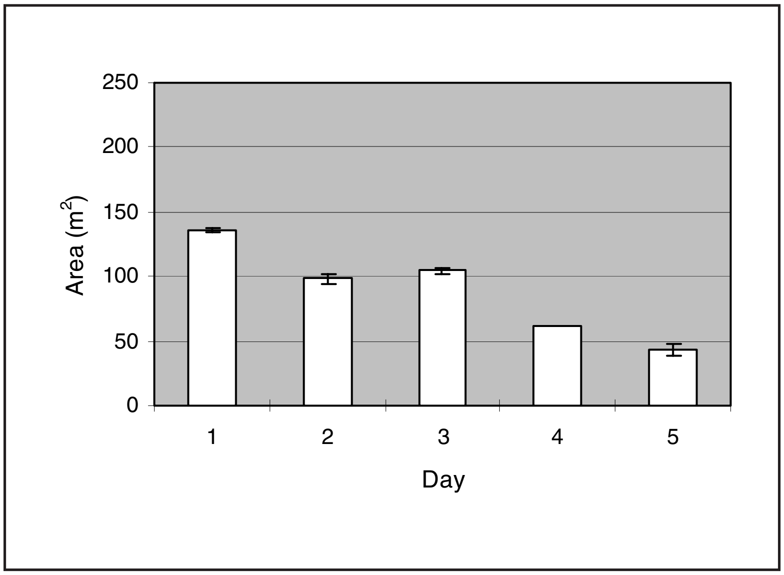

Figure 4. Fall 1997: estimates of roost area. Error bars depict two standard deviations from the mean.

distant within days. Similarly, bats banded 400 miles away in other roosts were found in Bat Cave.

The opposite occurred during the fall of 1997 when daily estimates generally decreased (Figure 4); we believe fall migration was already in progress. Personal observations (all authors), and those of park naturalists, suggested that the resident colony appeared larger in 1997 than in 1996, although our area estimates indicate otherwise.

The fall 1996 session provided consistent estimates between observers and days ($CV_o < 6\%$, $CV_d < 8\%$) with no trends evident (Figure 2). This photo session is believed to be representative of the resident colony at that time and the data show the potential for the RIP technique. Repeated within season, the technique has the distinct advantage of providing confidence intervals and thus statistical comparisons between years. This makes it a good tool for evaluating long-term trends.

The timing of photo sessions is critical in order to avoid migratory movements that could severely misrepresent abundance. Our data indicate that the time between arrival of the entire colony from Mexico and when females give birth is extremely short.

Shadows on some photographs may have resulted in greater estimates when observers counted them as a patch of bats. In 1997 we added a second flash unit to reduce shadowing. In the future we can further decrease the potential for this error by using reference photographs of the ceiling without bats. Fortunately, the potential to overestimate is balanced somewhat by bats that roost in cracks which are not photographed and thus not counted.

Individual ceiling height measurements were accurate; however, the nonrandom selection of few measurements (n = 3 for each photo-point) may have resulted in biases. This is potentially our greatest source of error. The degree of bias would depend on ceiling geography and colony arrangement. We believe this to be minimal during 1996 and 1997 because of the similarity in colony arrangement between years, but we recognize this as a concern. We are currently creating contour maps of the ceiling using laser survey technology. These contour maps will be digitized to form a base map in a Geographic Information System (GIS). Photographs of the ceiling will be referenced to the base map in order to calculate area estimates of bats more accurately.

There are few data on roosting densities of Mexican free-tailed bats, and there are no data specific to Carlsbad Caverns. We attempted to use a telephoto lens to evaluate roosting density in Bat Cave, but the 24 to 30 meter high ceilings and complete dark prevented us from obtaining usable images. The density estimate we used—2,153 bats/square meters—is conservative, although it was probably not constant during the photo sessions. Further research is necessary to estimate roosting density specific to Bat Cave.

Accurate estimates are seldom attainable for large populations of free-ranging wildlife. For monitoring, investigators often resort to techniques which may be inaccurate, but are unbiased, repeatable, and provide a measure of statistical precision (e.g., confidence intervals) so that year-to-year trends can be determined. Furthermore, given that accuracy is a problem, investigators strive to underestimate rather than overestimate abundance. This reduces the chance of careless management that could lead to population declines. The RIP method is reasonably unbiased and provides a conservative estimate of abundance. We demonstrated the repeatability of the method with consistent estimates between observers. Additionally, the photographs are permanent records of the colony, and if more reliable estimates of roosting density are obtained, our estimates can be adjusted.

The method is easy to apply and the camera mount system assures consistent photographs for each point. Processing photographs requires experience, but professional services are available. The method is relatively inexpensive so that it can be done every year. Similar techniques are currently being developed at other caves (e.g., Bracken Cave, B. Keeley personal communication) so that regional comparisons may be obtainable in the future.

Recommendations

Carlsbad Caverns National Park should continue to refine the RIP technique. Specifically, we recommend the following improvements:

1. Contour maps of the cave ceiling should be completed to reduce error associated with inaccurate ceiling area measurements. These maps should be digitized and used with digitized photographs of bats for accurate coverage estimates.
2. A photo session should be conducted from July 15th through July 30th. Possibly, this is the best time to get a single estimate of abundance for the resident colony. Pre-birth and pre-migration estimates would be ideal; however, it is likely that timing will always be a problem. Estimates in the spring and fall could always be subject to migratory individuals from other roosts and from early or late migration of the resident colony. A late July session would include all adults and young-of-the-year just as they are beginning to fly.
3. If time and money allow, the spring and fall sessions should be continued, but photo sessions should be conducted later in the spring and earlier in the fall. During normal years, birthing begins about mid-June and ends by mid-July. Few bats flew during our photo-sessions, and we are confident disturbance was not a problem; thus, a photo-session from June 10th through June 15th might provide good estimates of pre-birth abundance without adversely affecting pregnant females. A fall session could be completed in early August.
4. Reference photographs of the cave ceiling without bats should be available for observers counting grid squares. This would eliminate any potential for shadows being counted as bats.
5. Further research should be conducted to look into the roosting density of Mexican free-tailed bats at Carlsbad Caverns during different times of the year. If differences are found from those we used, past estimates could be recalculated.
6. Staff at Carlsbad Caverns National Park has been testing the use of flight noise recording (FNR) as an index to population trends and this should be continued. A remote microphone and data logger allow continuous recording of flight noise over a 24-hour period. The data are then graphed and the area under the curve serves as an index to abundance. Over the next four years the RIP and FNR techniques should be done simultaneously to correlate the two techniques.

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