The Bio/Diversity Project is made possible by generous funding from the Agnese Nelms Haury Program in Environment and Social Justice
The Bio/Diversity Project emerged as a collaborative endeavor by four Tucson, Arizona organizations dedicated to conservation and science education: the Arizona-Sonora Desert Museum, the Friends of Saguaro National Park, Saguaro National Park, and the University of Arizona Women in Science and Engineering Program. After a successful year of coordinating bioblitzes at local schools, the organizations decided that more sustained engagement with K-12 schools was necessary to attain the transformative effect that they had envisioned. With generous funding from the Agnese Nelms Haury Program in Environment and Social Justice, they came together to create the Bio/Diversity Project. The overarching goal of the Bio/Diversity Project is to create a K-16+ and into the workforce pipeline that is aimed at diversifying the environmental sciences and increasing the diversity of voices included in discussions of environmental problems and their solutions. Read more about the partner organizations below.

**Arizona-Sonora Desert Museum**

The Arizona-Sonora Desert Museum was founded in 1952 and is recognized throughout the world as a model institution for innovative presentation and interpretation of native plants and animals that are featured together in ecological exhibits. The Museum is regularly listed as one of the top ten zoological parks in the world due to its unique approach in interpreting the complete natural history of a single region (in our case this is the Sonoran Desert and adjacent ecosystems). This represents a significant achievement, as the Museum’s collections and size are smaller than many of its counterparts. Not a “museum” in the usual sense, it is an unparalleled composite of plant, animal, and geologic collections with the goal of making the Sonoran Desert accessible, understandable, and valued.

Today, this approach can be most easily understood by noting that the Museum’s living animal collection contains 4,892 specimens of 242 species. Plants number 56,445 specimens of 1,100 taxa; mineral and fossil collections include 16,853 specimens. The living collections also contain 110 to 120 species that are considered to be of conservation concern.

The Museum tries to find ways to enlarge its reach, whether this is in school and community education programs in urban and rural areas of Arizona, Sonora, and Baja, through publications, or through electronic communication. Today, the Museum's conservation and research programs are providing important information to help conserve the Sonoran Desert region, and the Desert Museum's Art Institute inspires conservation through art education and gallery exhibits. The Museum's publishing division, ASDM Press, has produced over 40 books and guides on the natural and cultural history of the Sonoran Desert region.

The Desert Museum is open 365 days per year and serves schools through field trips and live animal outreach programs. For more information about the Arizona-Sonora Desert Museum, visit [https://www.desertmuseum.org/center/edu/](https://www.desertmuseum.org/center/edu/)
Friends of Saguaro National Park

Friends of Saguaro National Park (FOSNP) is a not-for-profit fundraising partner of the National Park Service that was created to help preserve, protect and enhance the fragile environment and unique cultural heritage of the Sonoran Desert at Saguaro National Park. Friends of Saguaro’s mission is to help protect natural and cultural resources, preserve native landscapes, promote environmental education, improve recreational trails, enhance visitor experiences, strengthen community partnerships, and build environmental stewardship for Saguaro National Park through philanthropy, education, volunteerism, and public awareness.

Since its founding in 1996, FOSNP has sought to establish collaborative partnerships within the Tucson community, develop a broad donor base, and provide both funding and volunteer support for some of the Park's most critical needs. For six straight years, the organization has been recognized by GreatNonprofits for its status as a "Top-Rated Nonprofit" during the annual "Green Choice" campaign, which is a distinction that is achieved by fewer than 1% of nonprofits nationwide.

By providing critical financial support and growing public awareness, Friends of Saguaro provides a vital link between Saguaro National Park and the Tucson community – and helps protect what Theodore Roosevelt described as "the most glorious heritage a people have ever received" – the lands and resources that have helped to define our vision and values as a nation.

For more information about Friends of Saguaro, visit http://www.friendsofsaguaro.org/

Saguaro National Park

Saguaro National Park was first established in 1933 for the purpose of protecting the giant saguaro cactus (Carnegia gigantean) and the associated Sonoran Desert and Sky Island ecological communities. Following several park expansions in subsequent decades, the National Park Service today works to preserve desert, mountain, and riparian habitats in the Tucson and Rincon Mountains, as well as the largest roadless Sky Island in North America – all of which encompasses a wide range of elevations that support extraordinary biodiversity. 78% of the Park's 91,327 acres are federally-designated wilderness – and the Park must preserve and protect its wilderness qualities while promoting understanding (and stewardship) of its natural and cultural resources through appropriate scientific research.

Saguaro National Park protects a superb example of the Sonoran Desert ecosystem, and features exceptional stands of saguaro cacti, fragile wildlife habitat, critical riparian areas, and the associated Sky Island mountain areas. The Park also preserves significant cultural resources, including national-register-listed or national-register-eligible archeological resources, places important to Native American cultural traditions, and historic structures. The Park provides exceptional opportunities for visitors to experience solitude and discover nature on their own, to educate people through close interaction with the environment, and to see the outstanding and diverse scenic features of this classic desert landscape.

Learn more by checking out the Park's website at http://www.nps.gov/sagu/
University of Arizona Women in Science and Engineering Program

The Women in Science and Engineering (WISE) Program was established at the University of Arizona in 1976 as part of the Women's Studies Department and the Southwest Institute for Research on Women. WISE aims to increase interest and diversity in the fields of social and natural science, technology, engineering, mathematics, and medicine by offering a variety of outreach programs and student engagement opportunities. In doing so, the program works to motivate students to enter careers in STEM fields and to support them along the way. It is the firm belief of WISE that greater diversity produces both better science and science that is better equipped to address some of the most pressing problems we face in the world today.

Since 2015, WISE has worked with organizations and schools throughout the Tucson metro area to increase interest and diversity in the environmental sciences. Our ability to grapple with some of the most pressing problems of the 21st century requires that we include a diversity of voices in discussions of environmental problems and the development of their solutions. Creating inclusive and diverse environmental science communities necessitates exposing youth to innovative, engaging environmental science programming and offering them support along their educational journeys. By providing programming along the K-16+ educational pipeline, WISE hopes to inspire the next generation of environmental scientists and change-makers.

For more information about the programs that are offered, visit the WISE website at http://wise.arizona.edu/
# Table of Contents

**Introduction**
- The Bio/Diversity Project

**The Importance of Diversity in the Environmental Sciences**
- Diversifying the Environmental Sciences
- Why Are Our Parks So White?
- “Doing” Science Versus “Being” a Scientist: Examining 10/11-Year-Old Schoolchildren’s Constructions of Science Through the Lens of Identity
- Relevant: Beyond the Basics
- Culturally Relevant Teaching in Science Classrooms: Addressing Academic Achievement, Cultural Competence, and Critical Consciousness
- 3 Tips to Make Any Lesson More Culturally Responsive

**The Science and Policy of Biodiversity**
- Basics
  - Biodiversity: The Variety of Life that Sustains Our Own
  - Conservation of Biodiversity
  - 2010 and Beyond: Rising to the Biodiversity Challenge
- Agriculture
  - Biodiversity
  - Native American Gardening: The Three Sisters and More
- Climate Change
  - Causes and Consequences of Biodiversity Declines
  - The Planet is Heating Up Faster Than Species Can Migrate
- Policy Across Scales
  - [Local] Sonoran Desert Conservation Plan Pima County, Arizona

**Our Local Habitat: The Sonoran Desert**
- The Sonoran Desert: Background Information
- Plant Ecology of the Sonoran Desert Region
- Adaptations of Desert Amphibians & Reptiles
- The Desert Adaptations of Birds & Mammals

**Culture and the Environment**
- Native Knowledge in the Sonoran Desert Region: People in the Sonoran Desert
- Human Ecology of the Sonoran Desert
The Schoolyard Bioblitz

Background

National Geographic Bioblitz.................................................................
Measuring Biodiversity...........................................................................

Lesson Plan

The Schoolyard Bioblitz.................................................................................

Identification Tools

Plant Identification Basics...........................................................................
Resources for Learning and Teaching Plant Identification..........................
A Pictorial Key to the Order of Adult Insects..............................................

Appendix

Vocabulary List..........................................................................................
Breakdown of Science Standards in Arizona.............................................
Introduction
**The Bio/Diversity Project**

Women, Latino/a, and Native American populations are systematically under-represented among those receiving university degrees in environmental science related fields and those entering the environmental science workforce. Increasing diversity in environmental science fields and careers is necessary for ensuring that the pressing environmental challenges we will face in the 21st century are understood and addressed in ways that benefit the most marginalized members of our society. The Bio/Diversity Project works to increase the diversity of voices included in discussions of environmental issues and the development of solutions to address them, by fostering the entry and success of under-represented populations in environmental science disciplines along a K-16+ educational pipeline and into the environmental science workforce.

A key component of this project is working with university-level students and local K-12 educators to expand environmental science programming at K-12 schools. This manual will serve as a guide for University of Arizona student interns and K-12 partner teachers, and will provide valuable information on the science of biodiversity, the importance of diversity in the sciences, the Sonoran Desert ecosystem, and the relationships between culture and environment that shape the biodiversity of local habitats.

**Program Goals**

- Increase K-12 student interest in and knowledge of environmental science topics, namely biodiversity, and careers
- Increase K-12 student access to innovative, experiential environmental science educational opportunities
- Increase positive science identity, motivation, and self-efficacy among K-12 student participants
- Improve science communication skills among university student participants
- Build positive relationships between partner organizations and K-12 schools and teachers

**Our Funding**

This program is made possible by generous funding from the Agnese Nelms Haury Program in Environment and Social Justice. The Haury Program supports an array of programming to further research, education, and partnerships for socially just solutions to environmental problems.
The Importance of Diversity in the Environmental Sciences
Since the 1990s, policy makers, educators, and social activists have drawn attention to prevalent gender and racial disparities in STEM fields and careers. Women and members of certain racial and ethnic groups (e.g., Latino/as, African Americans, Native Americans) are systematically underrepresented among those receiving undergraduate and graduate degrees in STEM fields and those entering and persisting in the STEM workforce. While a variety of efforts have been made to encourage the entry and success of underrepresented groups in STEM fields, research by US News and Raytheon shows remarkably little progress was made in decreasing racial and gender disparities between the years 2000 and 2015. In some cases, we’ve actually seen a decline in the number of women and people of color in certain fields. For example, fewer African American men are in medical school today than there were in 1975 and the percentage of women pursuing computer science degrees has declined by nearly 20% since the early 1980s.

In 2011, despite the fact that African Americans represented 11% of the overall workforce, they made up only 6% of the STEM workforce; similarly, Hispanics accounted for 15% of the overall workforce, but only 7% of the STEM workforce (Figure 9). According to the American Community Survey, women, who make up nearly half of the working population in the United States, only comprised 26% of STEM workers in 2011 (Figure 5) (Landivar 2013). These types of racial and gender disparities in the workforce have been linked to a variety of factors including: inequitable educational opportunities; gender and racial stereotypes; implicit bias; sexual harassment and discrimination; and a lack of role models from diverse racial, ethnic, and gender groups.

Figure 9.
Racial and Ethnic Representation in the STEM Workforce
(In percent. Data based on sample. For information on confidentiality protection, sampling error, nonsampling error, and definitions, see www.census.gov/acs/www/)

Note: Native Hawaiian or Other Pacific Islander alone was combined with Some Other Race because of a small number of sample observations.
Source: U.S. Census Bureau, 2011 American Community Survey.

Graph source: Landivar, 2013, American Community Survey Reports
Figure 5.
Women's Employment by Detailed STEM Occupations
(Data based on sample. For information on confidentiality protection, sampling error, nonsampling error, and definitions, see www.census.gov/acs/www/)

Total employed
Total STEM occupations
Computer occupations
Computer and information systems managers
Computer and information research scientists
Computer systems analysts
Information security analysts
Computer programmers
Software developers
Web developers
Computer support specialists
Database administrators
Network and computer systems administrators
Computer network architects
All other computer occupations
Mathematical occupations
Actuaries
Mathematicians
Operations research analysts
Statisticians
Miscellaneous mathematical science occupations
Engineering occupations
Architectural and engineering managers
Surveyors, cartographers, and photogrammetrists
Aerospace engineers
Agricultural engineers
Biomedical engineers
Chemical engineers
Civil engineers
Computer hardware engineers
Electrical and electronics engineers
Environmental engineers
Industrial engineers, including health and safety
Marine engineers and naval architects
Materials engineers
Mechanical engineers
Mining and geological engineers
Nuclear engineers
Petroleum engineers
All other engineers
Drafters
Engineering technicians
Surveying and mapping technicians
Sales engineers
Life and physical science occupations
Natural sciences managers
Agricultural and food scientists
Biological scientists
Conservation scientists and foresters
Medical and life scientists
Astronomers and physicists
Agricultural and food science technicians
Biological technicians
Chemical technicians
Geological and petroleum technicians
Nuclear technicians
Atmospheric and space scientists
Chemists and materials scientists
Environmental scientists and geoscientists
All other physical scientists
Misc. life, physical, and social science technicians
Social science occupations
Economists
Survey researchers
Psychologists
Sociologists
Urban and regional planners
Misc. social scientists and related workers
Social science research assistants

Source: U.S. Census Bureau, 2011 American Community Survey.

Graph source: Landivar, 2013, American Community Survey Reports
While discussions of diversifying STEM fields have become relatively common-place, some fields receive more attention than others. Engineering, computer science, physics, and mathematics, for example, have received sustained attention by governmental and non-governmental organizations alike. Environmental science, however, is often not explicitly named in discussions of STEM diversity, but data indicates that it currently lacks gender and racial/ethnic diversity.

According to the National Science Foundation, in 2011 only 7.8% of the undergraduate degrees awarded in the Natural Sciences and 5.1% of those awarded in the Earth Sciences were given to Hispanic/Latino individuals, and less than 1% to Native Americans or Alaskan Natives in both fields (National Science Foundation 2014). At the same time, women received only 40% and 4% of degrees awarded in Earth Science and Natural Science, respectively, despite making up more than 50% of those receiving undergraduate degrees nationally (ibid). At the University of Arizona in 2015, only 0.3% of those majoring in the environmental sciences were Hispanic and there were no Native American environmental science majors. The lack of diversity in environmental science disciplines at the university level carries over into the environmental science workforce nationally (Figure 14) and locally in southern Arizona. Tucson, for example, has a population that is 44% Hispanic, yet 75% of the employees at the local National Park - Saguaro - are white, and the majority are male.

Recent media reports have also highlighted the hostile work environments experienced by women who work in the environmental sciences. From university labs where sexual harassment is rampant, to backcountry jobs where the potential of sexual assault haunts women workers, women face unique challenges in both entering, persisting, and succeeding in male-dominated environmental science careers.

---

**Figure 14.**

**Share of Total Employment, Science and Engineering Degrees, and STEM Employment by Sex**

(In percent. Data based on sample. For information on confidentiality protection, sampling error, nonsampling error, and definitions, see www.census.gov/acs/www/)

<table>
<thead>
<tr>
<th>Gender gap (in percentage point)</th>
<th>Total workforce</th>
<th>Science and engineering graduates</th>
<th>STEM workforce*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male</td>
<td>52</td>
<td>61</td>
<td>76</td>
</tr>
<tr>
<td>Female</td>
<td>48</td>
<td>39</td>
<td>24</td>
</tr>
</tbody>
</table>

*With a science or engineering bachelor’s degree. Source: U.S. Census Bureau, 2011 American Community Survey.

Graph source: Landivar, 2013, American Community Survey Reports
Why Diversity?

While it is clear that the environmental sciences lack a gender and racial/ethnic diversity that is representative of the US population, this does not address the question of why we should work towards creating more diverse environmental science communities. So, why is diversity important? What benefits come from having a greater diversity in scientific communities in general, and also among those examining particular environmental issues?

There are a number of reasons why fostering more diverse scientific communities is desirable. The more diverse these communities are, the more innovative and capable they are of tackling challenging problems. Research on diversity in the sciences has illustrated that gender and racial/ethnic diversity within scientific communities is necessary for ensuring that the benefits of scientific pursuits are justly distributed across the population (Harding 2006). By including a diverse set of voices in discussions of environmental problems and their solutions it helps to ensure that the needs of the most marginalized members of society, who are often those most affected by environmental problems, are addressed. Fostering the entry and success of individuals from groups that are underrepresented in the environmental sciences is important in developing innovative solutions to environmental challenges and helping to ensure that these solutions are capable of improving the lives of all members of society. Moreover, a lack of diversity in the environmental sciences indicates that there is inequitable access to educational opportunities in the sciences for different gender and racial/ethnic groups.

Fostering Diversity: Science Identity, Motivation, and Self-Efficacy

Research shows that young people begin to identify or dis-identify with science and math as early as 10 years old. For many students there is a marked disconnect between enjoying science – ‘doing science’ – and identifying with science or identifying as a scientist – ‘being a scientist’ (Archer 2010). This disconnect is most pronounced among girls and students from racial and ethnic groups that are underrepresented in the sciences. As students come to understand themselves as gendered and racialized beings, their ability to identify with science and as scientists is linked to how their personal identities map onto their visions of what scientists look like. This means that fostering interest, success, and persistence in the sciences among underrepresented students requires challenging narrow notions of what a scientist looks like, or of who can be a scientist.

Providing students with positive STEM role models that are ethnically and gender-diverse is one way to counter these narrow understandings of science and scientists. Additionally, by linking scientific issues, methods, or processes to student interest, educators can help make science seem more relevant and important to students.

Due to systematic methodologies that exist in school systems though, certain challenges exist in integrating these methods into science classrooms. Traditional science textbooks and curriculum often implicitly take a Eurocentric and masculinist viewpoint – white and male individuals are overrepresented in examples of key scientific figures, and Western cultural beliefs and values (e.g., white, middle-class) dominate how scientific topics are framed and discussed. Furthermore, a deficit model often guides educational program development, where non-white and female students are seen as lacking – in resources, access to opportunities, and knowledge. While a number of structural factors create educational inequities that often manifest in gendered and racialized ways, this type of deficit model of education fails to acknowledge the unique and valuable knowledge, skills, and resources that marginalized students bring to the classroom.
Research on diversity and science education has identified a number of strategies that are effective at increasing student interest and success in STEM fields and careers. Providing students with diverse role models, offering interactive activities that make science fun and relatable, and offering opportunities for students to interact with scientists have all been shown to positively affect student interest and persistence in STEM fields. Moreover, providing opportunities for students to see the real-world relevance of scientific knowledge and processes has increased student interest in science, especially among students from groups that are traditionally underrepresented in these fields.

In response to the gender and racial/ethnic diversity issues in the environmental science workforce, the K-12 outreach component of the Bio/Diversity Project will strive to increase student access to hands-on environmental science educational opportunities and to foster the development of science identity, motivation, and self-efficacy in local students. University of Arizona student interns will be paired with K-12 teachers to develop culturally-relevant and place-based environmental science lessons that focus on the overarching theme of biodiversity. In order to provide K-12 students with diverse STEM role models, special attention will be paid to recruiting UA student interns from groups that are underrepresented in the environmental sciences.
Why Are Our Parks So White?

By GLENN NELSON    JULY 10, 2015

SEATTLE — MOUNT RAINIER stands sentry over Seattle. On clear days, the mountain is the dominant backdrop, particularly in the city’s southeast, where its most racially diverse neighborhoods embrace their majestic setting with names like Rainier Valley and Rainier Beach.

Michelle Perry lives in an adjoining neighborhood and travels to work on Rainier Avenue South. The looming mountain enchants and beguiles nearly the entire way. She knows she can keep driving south and visit Rainier and the national park that surrounds it. Ms. Perry, 58, an African-American, has an idea about what she’d find up there — mosquitoes, which she hates, and bears, cougars and wolves, which she fears.

“The mountains are beautiful to watch,” she said, pausing for effect, “from a distance.”

As it approaches its centennial on Aug. 25, 2016, the National Park Service says it wants to encourage people like Ms. Perry to visit. It has its work cut out for it.

The national parks attracted a record 292.8 million visitors in 2014, but a vast majority were white and aging. The most recent survey commissioned by the park
service on visitation, released in 2011, found that 22 percent of visitors were minorities, though they make up some 37 percent of the population.

This suggests an alarming disconnect. The Census Bureau projects that the country will have a majority nonwhite population by 2044. If that new majority has little or no relationship with the outdoors, then the future of the nation’s parks, and the retail and nonprofit ecosystem that surrounds them, will be in trouble.

Jeff Cheatham grew up in southeast Seattle, and still lives in Mount Rainier’s shadow. Yet, he said of Mount Rainier and other national parks, “I’ve never been, and never thought about going.” A 29-year-old African-American writer, Mr. Cheatham said he didn’t even know what a national park was, or what he would be likely to find at one. “As far as I know, it’s a big field of grass,” he said.

A neighbor, Carla DeRise, has been to Mount Rainier and other parks, and is game to go again. She just can’t get any of her friends to come along. They are worried about unfriendly white people, hungry critters and insects, and unforgiving landscapes, said Ms. DeRise, 51, an African-American. So she mainly hikes alone, albeit with some anxiety. “I don’t have a weapon,” she quipped. “Yet.”

I also live in one of the Rainier neighborhoods, close to where I grew up, the son of a Japanese mother. I met my oldest friend in the Boy Scouts, an African-American from a family that, like mine, frequented the parks. In college, he and I led outings for minority student groups.

There was always nervous banter as we cruised through small rural towns on our way to a park. And there were jokes about finding a “Whites Only” sign at the entrance to our destination or the perils of being lynched or attacked while collecting firewood after the sun went down. Our cultural history taught us what to expect.

This is part of what the park service is up against, which may help explain why so many minorities say they know little about the nation’s parks or what to expect when visiting them. In the 2011 park service survey, nonwhites were more than three times as likely as whites to say that the parks provided poor service and were not safe to visit.
And those responses were from nonvisitors, which means that perceptions had congealed into reality among what should be an important constituency for the parks.

We need to demolish the notion that the national parks and the rest of nature are an exclusive club where minorities are unwelcome.

The place to start is the National Park Service. About 80 percent of park service employees in 2014 were white. The parks’ official charity, the National Park Foundation, has four minority members on its 22-person board.

Minorities did not exceed 16 percent of the boards or staffs of some 300 environmental organizations, foundations and government agencies included in a 2014 study for Green 2.0, an initiative dedicated to increasing racial diversity in such institutions. Minorities hold fewer than 12 percent of environmental leadership positions, and none led an organization with a budget of at least $1 million, the study found.

The National Park Service is the logical leader to blaze a trail to racial diversity in the natural world. It has a high public profile, and its approaching centennial can serve as a platform for redefinition.

But the agency has so far missed the opportunity. It doesn’t even know how many minorities visit the parks these days because it doesn’t routinely track such information. Its initial centennial-related campaign, Find Your Park, includes but doesn’t specifically target minorities and was delivered mainly to the already converted.

Efforts like handing park passes to fourth graders and their families, firing up Wi-Fi in visitor centers, and holding concerts on seashores or valley floors will similarly miss the mark. The park service should use its resources and partnerships to execute an all-out effort to promote diversity within its ranks and its parks. Its outreach should be tailored to minorities and delivered where they log in, follow, Tweet, view or listen. The park service needs to shout to minorities from its iconic mountaintops, “We want you here!”
Such a campaign could include educational programs about the importance of the outdoors to a healthy lifestyle, transportation solutions for carless urban dwellers, and advice on easy and safe ways to enjoy the parks.

The national parks are every American’s vacation home. My wife and I have immigrant mothers who view ownership of the national parks as a grand perk of their naturalized citizenship. Such entitlement must be nurtured in underserved communities. As the world becomes more urbanized, it is increasingly essential to preserve the outdoors as a respite for everyone.

This notion begs for a ubiquitous marketing effort: “I am (hiking/camping/fishing) in my own backyard,” set in various parks and with people of different backgrounds.

We need to inspire people like Jordan Quiller, a 21-year-old African-American who had never seen a mountain until he moved into one of the Rainier-monikered Seattle neighborhoods at the end of last year. He’s never visited a national park, but would like to.

Three national parks lie within a three-hour drive of Seattle. “It takes a little planning,” Mr. Quiller said. “I just haven’t gotten around to it.”

I hope the National Park Service and its partners are listening.

The founder of The Trail Posse, a website that encourages diversity in the outdoors.

Follow The New York Times Opinion section on Facebook and Twitter, and sign up for the Opinion Today newsletter.

A version of this op-ed appears in print on July 12, 2015, on page SR4 of the New York edition with the headline: Why Are Our Parks So White?.

© 2016 The New York Times Company
“Doing” Science Versus “Being” a Scientist: Examining 10/11-Year-Old Schoolchildren’s Constructions of Science Through the Lens of Identity

LOUISE ARCHER, JENNIFER DEWITT
Department of Education and Professional Studies, King’s College London, London SE1 9NH, United Kingdom

JONATHAN OSBORNE
Stanford University School of Education, Stanford, CA 94305, USA

JUSTIN DILLON, BEATRICE WILLIS, BILLY WONG
Department of Education and Professional Studies, King’s College London, London SE1 9NH, United Kingdom

Received 16 October 2009; revised 16 February 2010; accepted 7 March 2010

DOI 10.1002/sce.20399
Published online in Wiley InterScience (www.interscience.wiley.com).

ABSTRACT: The concern about students’ engagement with school science and the numbers pursuing the further study of science is an international phenomenon and a matter of considerable concern among policy makers. Research has demonstrated that the majority of young children have positive attitudes to science at age 10 but that this interest then declines sharply and by age 14, their attitude and interest in the study of science has been largely formed. This paper reports on data collected as part of a funded 5-year longitudinal study that seeks to determine how students’ interest in science and scientific careers evolves. As an initial part of the study, six focus group discussions were undertaken with schoolchildren, age 10–11, to explore their attitudes toward science and interest in science, the findings of which are presented here. The children’s responses are analyzed through the lens of identity, drawing on a theoretical framework that views identity as an embodied and a performed construction that is both produced by individuals and shaped by their specific structural locations. This work offers new insights into the manner in which students construct representations of science and scientists.

Correspondence to: Louise Archer; e-mail: Louise.archer@kcl.ac.uk

© 2010 Wiley Periodicals, Inc.
INTRODUCTION

The issue of students’ engagement with science has been a topic of enduring interest in the science education community for the past three decades. Major reviews have been conducted by Ormerod and Duckworth (1975), Gardner (1975), Schibeci (1984), and Osborne, Simon, and Collins (2003). Yet very little work has been conducted on what views young students hold about science—particularly not from a qualitative perspective that understands learning as tied to processes of identity construction (Holmes, 2000). This work offers, therefore, new perspectives on an enduring issue for the field.

A considerable body of evidence now exists that, compared to other school subjects, science is failing to engage young people (Jenkins & Nelson, 2005; Lyons, 2006; Osborne & Collins, 2001; Sjøbeg & Schreiner, 2005). Yet, student interest in science at age 10 has been shown to be high and with little gender difference (Murphy & Beggs, 2005)—although stark gender differences emerge as children get older. In the United Kingdom, research has shown that the point of decline begins in the final year of elementary school (Murphy & Beggs, 2005). Indeed, Ormerod and Duckworth (1975) devote a whole chapter of their review on attitudes to science to the considerable body of work, which shows that interest in science is a product of student experiences by age 11, drawing on work conducted as early as 1874. This has been confirmed more recently by the longitudinal analysis of National Assessment of Educational Progress (NAEP) data between 1988 and 2000 conducted by Tai, Qi Liu, Maltese, and Fan (2006). Further recent evidence that children’s life-world experiences prior to 14 are the major determinant of any decision to pursue the study of science comes from a survey by the Office for Public Management (OPM) for the Royal Society (2006) of 1,141 science, engineering, and technology (SET) practitioners’ reasons for pursuing scientific careers. It found that just over a quarter of respondents (28%) first started thinking about a career in science, technology, engineering, and mathematics (STEM) before the age of 11 and a further third (35%) between the ages of 12 and 14. Likewise, a small-scale longitudinal study that followed 70 Swedish students from grade 7 (age 12) to grade 11 (age 16) (Lindahl, 2007) found that their career aspirations and interest in science were largely formed by age 13. Lindahl concluded that engaging older children in science would become progressively harder.

Such data demonstrate the importance of the formation of career aspirations of young people long before the point at which many make the choice about which subject to pursue at high school and then college. Thus, we would contend that effort could be productively expended by (a) understanding what are the formative influences on student career aspirations between the ages of 10 and 14 and (b) attempting to foster and maximize the interest of this cohort of young people, particularly girls, in STEM-related careers.

Our approach to exploring students’ engagement with science is grounded in notions of identity—an understanding that sees the lack of interest in school science as a product of the mismatch between popular representations of science, the manner in which it is taught, and the aspirations, ideals, and developing identities of young adolescents. Indeed there is a large body of work that would indicate that students’ sense of self-identity is a major factor in how they respond to school subjects (Head, 1985; Schreiner & Sjøbeg, 2007) and research has drawn attention to the ways in which identities (and inequalities) of gender, social class, and ethnicity can impact on students’ engagement with science (e.g., Brickhouse & Potter, 2001; Calabrese Barton & Brickhouse, 2006; Carlone, 2004; Carlone & Johnson, 2007; Mickelson, 1990; Springate, Atkinson, Straw, Lamont, & Grayson, 2008). Our theoretical approach draws on feminist poststructuralist (e.g., Butler, 1990; Francis, 2008), critical sociological (e.g., Bourdieu, 1990) and postcolonial (e.g., Bhabha, 1990; Hall, 1992) theorizations of identities and inequalities of gender, social class, and ethnicity.
Drawing across these bodies of work, we understand identity (and hence, gendered, classed, and racialized identities) as both embodied and performed constructions that are both produced agentically by individuals and shaped by their specific structural locations (e.g., Archer, 2003; Archer & Francis, 2007). Identities are understood, therefore, as discursively and contextually produced (i.e., produced through practices, relationships and interactions within specific sites and spaces)—and as profoundly relational. For instance, “masculinity” is necessarily produced in relation to “femininity” (and vice versa). That is, a sense of self is constructed as much through a sense of what/who one is not, as much as through the sense of who/what one is (Said, 1978). Importantly, notions of identity are multifaceted and complex, being shaped in relation to intersecting axes such as gender, ethnicity, and social class, which can generate powerful notions of what is/not appropriate or normal for “people like me”—which in turn can profoundly shape individuals’ educational choices and trajectories (Bourdieu & Passeron, 1977). Hence we suggest that children’s interest and engagement with science will be shaped by their social structural locations and the specifically classed and racialized masculine/feminine identities that (are produced within such locations and that) they see as desirable and constitutive of the self (for instance, the notion of “laddish” masculinity among working-class boys is employed later in the analyses).

This paper seeks to explore then how such research-informed approaches can help to understand and address key challenges in enhancing participation, engagement, and achievement in science and mathematics, in particular to address differences linked to socioeconomic status, gender, and ethnicity. In particular, the paper represents an attempt, at the start of our project, to set out potentially useful concepts to work with, and to map key avenues for exploration over the next 5 years.

Study Design and Sample

The data for this paper come from an ongoing 5-year longitudinal study (funded by the U.K. ESRC Special Initiative on Science and Mathematics Education) that aims to develop an understanding of the processes underlying the formation of young people’s aspirations and their engagement with science. Data for the larger project will consist of a quantitative survey (to be administered to approximately 9,000 students at age 10 and subsequently at ages 12 and 14) and qualitative, longitudinal tracking of 60 pupils and their parents over 4 years. To inform the design of the quantitative survey, six focus group discussions were conducted with 42 students drawn from four schools in the London area. These schools (detailed further below) were purposively selected to provide a sample of boys and girls from a range of backgrounds, representing a spread of socioeconomic status and ethnic diversity. The fundamental aim of these group discussions was to gather data on the topic and participants’ perceptions and understandings. Thus, in selecting our sample, we sought to recruit a selection of students from a range of backgrounds and types of school. Such research seeks to develop a deeper understanding of its central focus exploring not only what participants think but why they think it (Kitzinger, 1994). As such, the goal is not necessarily to produce data that can be generalized to larger populations, but rather to explore the range of attitudes, values, and beliefs that are held, and the strength of feeling and reasons underpinning these views and beliefs. While previous research suggests that data saturation is achieved after three to four discussion groups, generalizing to a wider population must always be undertaken with caution (Vaughan, Schumm, & Sinagub, 1996) particularly as we make no claim about the representative nature of our sample. Essentially, discussion groups seek to expose what Schutz and Luckman (1973) have termed “intersubjectivity”—the collective description of everyday reality and its variation. The data emerging from such
work provide a valuable tool for representing the world as it is perceived by the group and their interpretation of experience.

Students were sampled from four schools. Potential participating schools were approached from an existing list of school contacts held by the research team in relation to the criteria of attaining at least one affluent, independent school, at least one urban multiethnic school, and at least one small and one large state primary in the London area. The resultant participating schools were the four who agreed to our invitation. Consent forms were issued to parents’ of children in Year 6 at each school, and discussion groups were conducted with the 42 students who returned consent forms. As detailed below, these discussions were conducted with single-sex groups in two schools, where numbers allowed, and as mixed-sex groups in the other two schools.

Pseudonyms have been assigned to the participating schools. “Inner City Elementary” (1 × girls group with two White Irish and four Bangladeshi girls, 1 × boys group, one Black African and five Bangladeshi boys) is a small urban elementary school situated in an area of high social deprivation with a large immigrant population (particularly from Bangladesh, Pakistan, and Africa). Most of the students attending the school are eligible for free school meals, and many do not speak English as their first language. “Private Elementary” (1 × group seven boys, 1 × group seven girls; pupils all White apart from one Asian boy) is a large selective, fee-paying school (admitting children from age 3–16). It is located in an affluent area of the city, and the majority of the children attending the school are from White British backgrounds. “Roman Catholic Elementary” (1 × mixed-sex group, seven students from one White, one Arabic, one mixed-heritage, and four Black African backgrounds) is a large, popular (oversubscribed) school located in an inner city area of considerable deprivation. The main pupil groups are those from White British and Black African backgrounds, and the majority of those attending are baptized Catholics. It is a publicly funded faith school (receiving additional support from the Catholic Church). “Urban Elementary” (1 × mixed-sex group, all nine students in the group were members of the lunchtime science club, all from South Asian—specifically Bangladeshi and Pakistani backgrounds) is a large innercity school in which almost all students come from minority ethnic backgrounds (the largest group being those of South Asian descent), and a very high proportion speak English as an additional language. An above average proportion of students are eligible for free school meals. All the pupils in the discussion groups were largely representative of the ethnic and socioeconomic profile of their respective school populations.

For the purpose of the discussion groups, a set of questions was developed that formed a loose structure for exploring these young students’ views (discussion areas included: students’ views on science, scientists, and their school science classes; out-of-school interests and leisure pursuits; aspirations for the future (and influences on aspirations). Students were assured of the confidentiality of the data, and each group lasted for approximately 1 hour. The discussion groups were conducted by the second author (a White American woman, denoted as “Int”/Interviewer in data extracts) and were digitally audio-recorded and transcribed. In line with the study’s conceptual approach outlined earlier (in which identities and the social world are understood as discursively constructed), data were analyzed discursively using a Foucauldian analysis of discourse approach (Burman & Parker, 1993). This approach involves looking for the resources and repertoires that are employed within participants’ talk and which are drawn on in (and are constitutive of) their identity constructions. These are then analyzed as practices of power (and are interrogated to the extent that they are both constitutive of and constituted by/within particular regimes of power). In this paper, this analytic process was undertaken by the lead author, who searched the data iteratively to identify key themes and identity practices and performances.
by the young students. Transcripts were initially broadly coded according to each of the main discussion topic areas (e.g., “reasons students enjoy science at school,” “out of school interests,” “views of scientists”) and the content of these was then subcoded thematically (iteratively testing out emergent themes across the data set to establish “strength” and prevalence). These coded themes were then subjected to a more theoretically informed analysis (to identify practices of power and gendered, classed, and racialized discourses and identity practices/resources) to unpick the constructive elements (and the wider discourses that are evoked) within respondents’ talk.

“DOING” VERSUS “BEING”

Our analysis of the role of identity within children’s constructions of science is broken down into two major themes, namely “doing science” and “being a scientist.” These were not specific questions within the interview protocol but were identified within the analysis of the data as two broad, common structuring discursive distinctions within the children’s talk. As will be argued later, the importance of this conceptual distinction is that it explains these young students’ ability to both reportedly enjoy science (most did) and to yet not want to continue with science in their future careers—to “become” a scientist (most did not). Our analyses thus highlight a key dilemma, namely that children can report enjoying science (e.g., they may find it fun, exciting, important, and interesting), but they may still choose not to study it at higher level. As we shall argue, these two areas were comprehensively infused with issues of identity and were circumscribed by social class, ethnicity, and gender, such that some options, even at this age, are beginning to be ruled out as not only undesirable but even “unthinkable,” whereas other possibilities are understood as desirable only under certain conditions.

“DOING SCIENCE”: SAFETY VERSUS DANGER

Under our major theme of “Doing Science,” our data largely echoed what is known from the existing literature, namely that student interest in science at age 10 tends to be relatively high with little gender difference (Murphy & Beggs, 2005; Pell & Jarvis, 2001). Most of the children who took part in the discussion groups reported enjoying science at school. This enjoyment was predominantly framed in terms of the practical mastery of “doing” science, namely the “hands-on” elements of practicals and experiments, a preference that has also been noted in other work (e.g., Solomon, 1980; Osborne & Collins, 2001). We found across the discussion groups that the children’s attachment to this form of “doing” science was framed within a discourse that we have termed “danger vs. safety,” in which “real” science is constructed as “dangerous” (and exciting) and is placed in tension with school science (particularly elementary school science) due to the latter’s concern with “safety.”

Boys and girls both associated science with explosions and bangs, as one girl put it, “pouring liquids to make, like, an explosion.”

Int: . . . So if you had to explain what science is to somebody who’d never heard of it how would you explain it?
Boy: Bangs.
Int: Bangs?
Boy: Just to say it could hurt your ears.
Boy: It’s interesting and you won’t know what’s going to happen next.

(Inner City Elementary, boys)
While both boys and girls were likely to find this flamboyant and explosive nature of science interesting and engaging, there were suggestions of orientations that were differently gendered to this evocation of danger. For instance, one girl’s rationale for not wanting to continue with science in the future was, “I don’t want to get my head blown off by chemicals” (Inner City Elementary, girl). Indeed, girls were considerably less likely than boys to cite their interest in science as due to “explosions” (Jenkins & Nelson, 2005).

It was also notable that considerably more boys than girls spent time discussing the “dangerous” nature of science, which was juxtaposed with the restraints they felt were imposed by their schools in terms of “safety.” As one boy at Inner City Elementary explained, “science is the dangerous kind of experiments and in school we don’t do that stuff.”

Boy 1: It’s like a lot of real stuff, like the real scientists they do like chemical work—we just do like (inaudible)

Int: Mm, okay.

Boy 2: We do like the boring safe things, but they do experiments which are dangerous

(Urban Elementary, Science Club, mixed group)

Girl: They [Scientists] do more dangerous stuff than we do in school.

Boy: That’s what I was going to say, I was going to say that in school we kind of . . . . We can’t really go past the boundaries because it’s too dangerous. Sometimes it gets frustrating because you know that nothing’s really going to happen to you. But the school, obviously they want you to be safe and it kind of is annoying.

(Roman Catholic Elementary, mixed group)

The boys at the Private Elementary agreed, bemoaning that they are not allowed to do “really big experiments. . . like using acids and stuff” because “it’s a lot safer at school.”

It is interesting to note in these extracts how “real” science is already being constructed in gendered terms. While, among the sample of 10-year-old children, both boys and girls reported enjoying doing science, we can see here how they are starting to articulate a dominant discourse in which “grown-up” science is constructed in masculine terms: as “dangerous,” risky and potentially unpredictable (and hence, by implication, exciting and innovative). While the children do not consciously use the language of gender themselves, feminist theorists have discussed how such attributes are clearly gendered and are aligned with masculinity (Francis, 2000; Francis & Skelton, 2008). The distinction between “grown-up” science and school science (which, drawing on feminist poststructuralist theorizations of gender, becomes positioned through a binary opposition as “immature,” “not real science,” as “safe” and as feminized) also suggests that those boys and girls who are attracted to this discourse of science perceive that there is an identity gap that will be have to be endured or negotiated if they are to continue with science. That is, the children identify a disjuncture between an attractive, desired vision of “real” science and a less attractive version of school science that must be pursued to become a scientist in the future. The overlaying of gender onto this disjuncture creates an additional identity conundrum—namely that an engagement with a “feminized” form of science is the necessary path to achieving (a more desirable, higher status) masculinized identification.1 One boy at a Private Elementary also

---

1 The conceptualization of gender that we use does not treat gender as tied to particular sexed bodies, i.e., girls can identify with, desire and engage in performances of masculinity and vice versa with boys and femininity. Although dominant social power structures mean that boys tend to perform masculinity more consistently than girls and that these performances tend to be judged as more “authentic” (and vice versa with girls and femininity).
provided some indication of the identity work that he undertook to try to navigate this disjuncture, adding the justification that “well, if you think about it all good scientists have to start off at this stage.” It seems, therefore, that while these young children may not have comprehensive or detailed knowledge of what a future career in science might entail, they are tacitly learning from an early age that it is associated with masculinity.

As illustrated above, many boys positioned their elementary schools as spaces in which science is infantilized and “made safe” (see Skelton, 2001, on the dominant feminization of elementary schools). The “safe” elementary school was juxtaposed against the fantasy of secondary schools as places where more desirable and “real” (“dangerous”) science might take place. A number of children, especially boys, talked about their keen anticipation of secondary school as allowing them to (literally) “play with fire, like Bunsen burners” (Inner City Elementary, boys), “when we get to secondary school we might be able to use fire” (Roman Catholic Elementary, mixed group; see also Urban Elementary, Science Club, mixed)—an expectation often fulfilled and well captured by the eponymous article of Delamont, Beynon, and Atkinson (1988): “In the beginning was the Bunsen Burner.” The frisson of danger associated with secondary school science generated a sense of excitement and anticipation (“in secondary school it’s more dangerous,” “it’s better because they trust you with more dangerous chemicals, stuff like that”; “dangerous stuff like explosions, mixing acids together, seeing what different chemicals do to each other”).

It appears from these initial data that the boys have constructed a close (anticipated) alignment between popular masculine identities and secondary school science. While in some ways this is encouraging (because these students are imagining that they will become yet further engaged with science at secondary school), it also introduces the risk that they will be disappointed if the science they are presented with at secondary school fails to live up to their fantasy of danger. Indeed, evidence suggests that while secondary school science may initially contain some of these exciting elements, it quickly becomes more theoretical, demanding more writing than practical work (Osborne & Collins, 2001). Given the dominant popular equation of writing with “feminized” forms of learning (Skelton & Francis, 2008), it might be reasonable to assume that these boys’ disillusionment with the demise of the practical/spectacular nature of science will be even more pronounced.

One possible policy response might be to suggest that secondary school science be reformed in ways that would emphasize and play up its “dangerous” potential. This echoes wider educational policy initiatives in the United Kingdom, United States, and Australia that have arisen from the debate about boys’ underachievement, in which attempts have been made to increase boys’ engagement and attainment in particular areas (especially those that are “feminized,” such as English/literacy) by making them more “masculine,” and hence attractive to boys (e.g., schemes that use football to increase the appeal of literacy). Such approaches have attracted considerable feminist critique for playing into gender binaries, for reinforcing dominant (hegemonic) forms of masculinity and for having negative implications for not only girls but also “other” boys (not all boys identify with dominant forms of masculinity). Moreover, as we discuss further later, the conceptual binary that we have identified within the children’s talk between “doing science” and “being a scientist” would suggest that enjoyment of (and indeed, competency in) school science does not straightforwardly translate into the sense that one wants to (or could) “be” a scientist. In other words, increasing a pupil’s enjoyment of “doing” science will not necessarily translate into their uptake of a science identity.

2 Secondary schools in the United Kingdom take children from ages 11–16 or 11–18. There are comparatively fewer middle schools.

Science Education
Doing Science Outside School: “Being Naughty” or “Being Good”?

As we have so far discussed, most of the schoolchildren we interviewed felt that the science they practiced in school bore little or no relation to the science practiced in the “real” (grown-up) world. Indeed, criticisms of the gap between school science and “real” science are not new—and calls continue to be made to increase the “real-world” relevance of science to better engage young people (e.g., Calabrese Barton, Ermer, Burkett, & Osborne, 2003).

In the discussion groups, we asked the children whether they ever practiced science outside of school and found that many talked about performing their own “experiments” at home. This might be seen as a heartening endorsement that not only are these children interested in science in school but they are incorporating this interest into their leisure time. However, we also identified some distinctly classed and gendered patterns within these accounts of “doing science at home,” which might help explain some of the different, distinctive patterns of engagement with science that emerge in older samples of students. That is, the different ways in which these 10-year-old children engage with science in their leisure time may be indicative of some of the processes that feed into their differential likelihood to attain well and continue with science in the future. We have identified a distinction between those students who described their out-of-school science activities as informal and as part of having fun and being mischievous (being “naughty”) and those students who practiced science in a more formalized way, relating to recognized school science curricula, and whose activities we would interpret as feeding into the larger project of working on developing/enhancing their “good pupil” identities (being “good”). The following extracts exemplify the responses of those who talked about doing science out of school as something fun and “naughty”—the children are talking about what they like to do in their leisure time and if they ever do any science at home:

Boy: like at home going out and getting Coke, and then getting salt, going to my enemy’s house, and then I put salt in the bottle, then like shake it up and it will fizz up, and then I will knock on the door, they’ll open it, I open it—and that’s it!

(Inner City Elementary, boys)

Boy 1: I fill up a balloon and like blow it up on people.
Int: How is that science?
Boy 2: Because we can see how the H2O blows up and . . .
Int: Oh so it’s a water balloon?
Boy 1: . . . and causes an explosion and all that.
Boy 3: H2O is water.
Girl 1: I’ve got this set and it’s called (inaudible) and you do experiments with it.
Int: Okay, uhuh.
Girl 1: And like you like stick all the different (inaudible) the little powder bits in like a balloon and then it all blows out (inaudible)
Int: Oh cool yeah.
Girl 2: I use my “Grow my own Crystals” kit.
Int: You use your what?
Girl 2: Grow your own crystals.
Int: Oh yeah, yeah. What about you?
Boy 4: Um, sometimes I get some balloons when I’m bored, and like rub it on my jumper or rub it somewhere, and stick it on my head.

(Roman Catholic Elementary, mixed group)
There were numerous accounts across the groups (mostly, though not exclusively, voiced by boys) where students talked excitedly about practicing science in terms of creating “explosions.” As one boy from Inner City Elementary put it, “Science can be really fun, if you’re being naughty.” Indeed, putting Mentos (chewable mint sweets) into Coca Cola to make it fizz and explode was mentioned as a popular pastime among many of the boys we talked to (and indeed one of the girls at Roman Catholic Elementary). These activities clearly engaged the children and form part of the spectacular and “risky” vision of science that they were attracted to, as discussed earlier. As also illustrated in the above extract, the two girls mentioned more formalized engagements (e.g., the crystal growing set) than boys. The gendered aspect of this “naughty” engagement with science can be read as part of the young boys’ performances of “laddish” masculinity, a contemporary form of popular masculinity. “Laddish” masculinities are the subject of considerable interest and interrogation within the gender and education literature and have been identified as an international phenomenon (Francis, 1999; Jackson, 2002). While laddishness is usually discussed with reference to older samples of boys and young men, it has also been noted as an important identity practice/discourse within elementary pupils (Renold, 2005; Skelton, 2001)—albeit in a more immature form than its adult manifestation. “Laddishness” derives from the notion of the “lad”—a young man who performs a gender-traditional (or monoglossic, Francis, 2000) masculinity, who engages in hedonistic practices (such as drinking, womanizing), is confident, “cheeky,” “cocky,” mischievous and entertaining (enjoys “having a laugh,” “back chatting” teachers). The identity of the lad is oppositional to that of the studious “geek” or “nerd”—the lad is not studious or conscientious, he engages in public displays of “not working” and keeps any effort or school work strictly “under cover” (Frosh, Phoenix, & Pattman, 2001). As the literature suggests, laddish identities are not homogeneous (boys may perform some aspects but not others; laddish identities are not constant or consistent) nor are they solely restricted to boys (see Jackson & Tinkler, 2007, on the rise of the “ladette”). However, in the United Kingdom they do constitute a popular and pervasive discursive reference point and resource within many boys’ (and girls’) identity constructions.

While the children cited above do not embody the excesses of laddish identity, their youthful exuberance for the “naughty” and fun side of their informal engagement with science does point to the allure of such identities. Their talk suggests again (as in the preceding section), that for some boys, the most popular, fun, and accessible aspects of science are those aligned with hegemonic masculinity. Moreover, the nascent laddishness hinted at within the children’s accounts (albeit framed here as being mischievous) would suggest that this popular engagement with science through hegemonic masculinity will not necessarily translate into later formal academic engagement with science. This is because laddish performances of masculinity tend to be predicated on a distaste for schoolwork, which becomes more trenchant with age. Thus, our point is that, while these children’s accounts of a joyful engagement in out-of-school science can indeed be valued in their own right, this form of engagement may not necessarily extend to a continued formal educational engagement with science.

In contrast, some children (but particularly—though not exclusively—those from more “middle-class” backgrounds) talked about more formalized engagements with science outside of school—a discourse that we have characterized as “being good.” These children described reading reference books, owning microscopes, and playing with science sets (such as the experiment set and the “grow your own crystals” set mentioned by the girls in the preceding discussion extract and the magnet set commented on later). One boy (at Inner City Elementary) described helping his uncle who worked in a laboratory. These children...
also talked about trying to replicate experiments conducted at school when at home. For instance, a boy at Inner City Elementary talked about how he had dissected a flower at home and a boy at Roman Catholic Elementary explained “when we were in Year 5 someone mentioned salt water and see how long it would dissolve or something, so I went home and tried it.” The joy of learning about and practicing science was clearly something they took pleasure doing in their time at home:

Boy: Well I look up books for experiments and sometimes look stuff up about the ozone layer etc. So it’s much more different from school than I learn at home. But it’s also quite fun.

(Private Elementary, boys)

Boy 1: I’ve got a magnet set at home.
Int: Mm, okay yeah?
Boy 2: I’ve got a magnifying tele- . . . it’s a microscope that you connect to the computer, and you can see everything like snowdrops.

(Urban Elementary, Science club, mixed group)

While these children also describe their out-of-school science activities as fun, there is a discernibly different feel to the form of their engagement, as compared to the “naughty” explosions outlined earlier. These children’s engagement with science at home reflects a greater use of “cold” (formal, official) knowledge (Ball & Vincent, 1998), such as reference books and educational sets. This access to and comfort with cold knowledge has been found to be more common among the middle classes (Ball & Vincent, 1998). These activities, such as consulting reference books, replicating experiments taught at school, working with adults, using microscopes and educational sets, and so on, are more structured and closer in content and form to the formal learning that takes place within schools. As such, we would hypothesize that such practices are more likely to translate into cultural and educational capital (Bourdieu, 1986, 1990). That is, they contain a clearer potential to facilitate the children’s attainment and progress in school science and to nurture and feed into the children’s self-identifications (and indeed their teachers’ assessments of them) as “good students.” Indeed, we might even read these instinctive engagements with out-of-school science in light of sociological theorizations of classed parenting and childcare practices, which have been linked to the production of classed patterns of educational advantage and disadvantage. Working-class family practices tend to be associated with the “accomplishment of natural growth” (Lareau, 2007), in which children’s development is not the subject of excessive intervention (to which we might map on those children’s instinctive and unstructured engagements, epitomized by the “Mentos in Coke” explosions, which tended to be conducted by children playing among themselves, rather than under adult supervision or tutelage). In contrast, middle-class families have been associated with more interventionist and structured approaches, a “concerted cultivation” (Lareau, 2007) of their children, often through an orchestrated program of educational “enrichment” activities (Vincent & Ball, 2007) that aim to develop a range of skills, interests, and capabilities within the child—which in turn help foster “success.” In this respect, we might read the “being naughty”/“being good” distinction in informal science practices as another field in which distinctions are germinating with regard to later patterns of achievement and engagement with science (see also Gladwell, 2008, regarding the significant advancements noted after
the summer vacation period for middle-class U.S. students compared to their working-class peers).³

As the following extract from the girls at Private Elementary illustrates, middle-class parents are more likely to utilize their cultural capital to generate opportunities for structured learning at home, such as buying books, science sets, and resources and seeking additional information from schools to enable them to support their children to do “proper” experiments at home.

Girl 1: And when my parents went to parents evening they managed to get a web site where you can like make sherbet and make (inaudible) and dissolve things, and it’s really interesting doing that.

Girl 2: Well I think it’s good cos we can, because we like made lava lamps . . . well ones that only work once. It was really funny cos they’re quite easy to make. But she just showed us how to make it and how it worked with olive oil and stuff.

Int: Oh wow.

Girl 2: And then it’s really easy to make at home.

(Private Elementary, girls)

One of the girls also talked about how “I experiment with lots of little things at home.” She described a science book she owned that she was working through at home (because “I can do science but I can’t do it perfectly”), which enabled her to “make experiments at home, like how to make putty.”

It was notable that it was only in the private (fee-paying) school that pupils mentioned explicit parental involvement in this way. This may indicate one of the many potential “small acts” and everyday practices that, over time and in sum, can help to foster higher levels of achievement and engagement with science among particular social groups.

Indeed, the potential importance of out-of-school interests and activities has been flagged elsewhere (Kelly, 1981; Ormerod & Duckworth, 1975; Woolnough, 1994). Mendick, Moreau, and Epstein (2009) conducted a survey with 560 Year 10 pupils from three comprehensives and 100 second year mathematics undergraduates in two universities and found that 40 Year 10 students rating themselves as “very good” at mathematics displayed a different and distinctive relationship to mathematics within popular culture. That is, they were “much more likely to play tetris and chess and to do sudokus and cryptic crosswords than other students” and were “most likely to carry on with maths” when it became optional at age 16. Indeed, it was notable that among our sample that the few children who embraced a potential future identity as a scientist linked this identity to their interests and activities at home (as opposed, for instance, to their interests or achievement at school):

Boy 1: I want to be um an inventor or . . .

Boy 2: Scientist.

Boy 1: . . . yeah scientist . . . or possibly an archaeologist.

Int: Ah, and why do you think you might want to be those things?

Boy 1: Because mostly at home I make inventions and stuff.

(Private Elementary, boys)

³ The other distinctions at work within the students’ constructions of their out-of-school science activities is the focus of forthcoming work, in which we explore the higher propensity for South Asian students in our questionnaire sample to undertake science activities at home.
“BEING A SCIENTIST”: THE SCIENTIST AS OTHER

We have so far explained that while the majority of 10-year-olds we talked with enjoyed “doing” science, the seeds of later distinctions and patterns of attainment and uptake of science are already becoming evident. In this section, we explore the limits of this boundary of “doing science” and the problematics of its translation into “being a scientist” (i.e., the taking up of a science identity). We will suggest that the main issue at stake here is the potential to construct and inhabit an intelligible science identity—one that is valued in and for itself, that is congruent with other aspects of a person’s identity, and that is also (seen to be) judged by others as being of worth.

Underlying our understanding of the reasons why an enjoyment of “doing” science may not translate into wanting to “be” a scientist is the argument that this disjunction is particularly likely to occur where science, as an identity discourse, is experienced as clashing with popular hegemonic forms of masculinity and femininity. Given that the latter are often intensely held identities, evoking strong emotional attachments, and experienced as profoundly personal identity constructions, it is unsurprising that they effectively “trump” the viability of a science identity. For instance, a boy in Roman Catholic Elementary school agreed that he found science “fun” but could not countenance becoming a scientist because, for him, it is “football and wrestling always”—an expression of the evident allure of hegemonic masculinity. Indeed, football and wrestling do not even have to achieve the status of being distinctive career goals—their mere possibility is sufficient: “I don’t want to be a wrestler—it’s just something that I like, that I might want to be a wrestler. I might not.” Girls also voiced highly gendered discourses in which they resisted the idea of becoming a scientist because “I don’t want to touch too many dead things” and “I wouldn’t like to see people like, their things and everything.. yeah and I’m not really into these science like skulls and ears and stuff” (Inner City Elementary girls). While a substantive literature already exists pertaining to the gendered construction of children’s aspirations and subject choices (Francis, 2000; Kelly, 1981; Lightbody & Durndell, 1996; Whitehead, 1996), we suggest that to understand the doing/being disjuncture further it is useful to look in more depth at the content of the children’s constructions of scientific identities and the ways in which these are not only gendered but are also inflected by social class and “race”/ethnicity.

Science as “Hard”/“Brainy”

Science was overwhelmingly constructed as a “hard” (difficult) subject that required and demands application. However, the hard or difficult nature of science was something that many of the students reported as attractive. For instance, the boys at Inner City Elementary complained of their frustration with a teacher’s attempt to make science “simple,” arguing that this rendered science less interesting.

Boy 1: She [teacher] knows a lot but it’s boring.
Int: Ah, the way she’s teaching it?
Boy 2: She doesn’t put emotions in it.
Boy 3: She tries to make it simple but she makes it so simple that she tells us all the stuff you already know.
Boy 2: Exactly.
Boy 1: It’s not interesting.
Boy 3: We like it when it’s so complicated we try to think it out with our brains, but she’s always like “I’m making it simple. If I do any simpler it would be cheating” and I’m like “We don’t want to cheat, so make it harder.” We want to test our brains.

Science Education
As the last comment above illustrates, these boys enjoyed the challenge of science as a “complicated” subject that requires students to use their “brains.” Indeed, the terms “brain” and “brainy” were highly prevalent across all the children’s transcripts (e.g., “it gets your brain going,” Inner City Elementary boy), which we would interpret as reflecting the status associated with subjects such as science, that are closely aligned with notions of intellectual rigor. This link (between the “braininess” of a subject and its social status) was made explicitly by the girls in the Private Elementary, who answered the question of what makes science fun saying “when we learn like the really brainy things, like the things you don’t learn if you’re in a state school.” These constructions are gendered and classed (being read as middle class and as masculine; see Harding, 1986) and hence are more likely to “fit” with middle-class students’ everyday notions of desirable masculinity and femininity, being especially appealing for middle-class boys. As one boy at the independent elementary school explained, what he liked about science was “when you learn stuff that you can like sound cool with.”

Children imagined that the science they would encounter in secondary school would be even harder and that this would be “a good thing” because it would require them to “use our brains more.”

Boy 1: But we’ve got to use our brains more. There are going to be a lot more harder questions and harder experiments to do
Int: Uh huh. Do you think that’s a good thing? A bad thing? Neither one?
Boy 1: I think it’s a good thing

(Roman Catholic Elementary, mixed group)

Although the notion of science as “testing your brain” was seen as attractive, one boy suggested that it can make your brain “kind of tired” with the risk that “you just get confused.”

The discourse of “science as hard” has been noted within other studies as a prevalent popular discourse, reproduced by students and teachers alike (see Carlone, 2004). However, while studies, such as Carlone’s, with older students have drawn out how this discourse of “science as hard” collapses into a discourse of “scientist as naturally clever/intelligent,” this link was not immediately evident within these children’s accounts. While “being a scientist” was in some instances linked with being intelligent (“I think their [scientists’] intelligence makes them good at their job”), the “brainy-ness” of science was configured in a complex relationship with effort and ability. These younger students argued that one need not be naturally “clever” to be good at science, even though it is a “brainy” subject. Rather, they felt that interest, application, effort, and “concentration” were more important (for instance, the Science Club children suggested ways of improving in science: “Just depends if you like it or not and whether you concentrate,” “Try and keep an open mind,” and “Don’t learn about just like certain subjects and topics, learn about all different topics”).

This sentiment (that one does not have to be “clever” to be good at science) was echoed across the discussion groups. While it is encouraging that these 10-year-olds had not reached the point of closing off science as the preserve of the “clever,” their discourse also contained contradictory elements, which point to how the dominant adult discourse (of science as for the “clever,” that has been found by numerous other studies) might come to be solidified among older students and adults. We suggest that this is encapsulated in their parallel discourse of science as “natural interest,” to which we now turn.

*Science Education*
Science as “Natural Interest”/Natural Ability

When asked what makes someone good at science, students across the groups overwhelmingly drew on a discourse of “natural interest” (“you have to be interested in all types of science”), arguing that the possession of this “natural interest” (liking and enjoying science) provides the motivation to pay attention, remember facts, and to do well in science classes. It also provides the impetus to engage in more, additional, learning about science.

Int: Do you have to be really clever to be good at science?
Boy: Sometimes when you’re like doing something, you can hear like interesting facts, or like really good stuff about science. . . . you can remember it and then, cos you heard that, you could get interested in science. And then you would study. . . . you would want to know more about science, so you look for more facts and more other stuff about science. And then you eventually. . . . you become really good at science

(Inner City Elementary, boys)

Girl: The most important thing a science person must have is they like science—that’s the most important thing. And if they like science, they have everything to do with science
Int: yeah?
Girl: They’ve just got to be able to enjoy themselves and not like say everything’s hard, they’ve just got to try and enjoy it

(Inner City Elementary, girls)

This theme, of liking science and possessing a natural interest in it, at first appears meritocratic: as long as a student is interested and motivated, they can do well at science. However, there were also suggestions that the discourse might, over time, slip into an essentialized, embodied manifestation—that is, the notion that there is a “science person”—the individual who is naturally interested in science and who has a science “mind”.

Int: What would you tell them if they wanted to be good at science? How would they do that?
Boy 1: They should learn. They should study on the weekends or after school. Do extra lessons maybe or tell the teacher you don’t understand and they will help you.
Girl: Yeah, try experiments, do experiments that they haven’t done before.
Boy 1: And share it with the class.
Boy 2: I think that you shouldn’t like be that eager to learn science to be very, very good, I think you should just do science like normally in life, and have fun with it and naturally you will graduate in your brain, your mind will go on. . . . it will increase in science.

(Roman Catholic Elementary, mixed group)

The last remark in the above extract hints at this notion: one should not be too “eager”; rather science should be undertaken “like normally. . . . have fun with it” and this will “naturally” increase both competence and interest in science. The emphasis on “naturalness” contains echoes of popular discourses in which science and mathematics are associated with particular sorts of people, the science person (Carlone, 2004) or the mathematics person.
“DOING” SCIENCE VERSUS “BEING” A SCIENTIST

(Mendick, 2006) who has a natural (innate?) ability and interest in science or mathematics and thus does not find it a chore or have to try too hard to learn about science or mathematics. The notion of there being a “science person” was also reinforced by several discussion groups’ references to other children in their schools or year groups who were known to be “good at science” or interested in science. Several groups of students mentioned in passing (there was no direct question on the topic) these other children who were known as being “science people.” For example, the children at Roman Catholic Elementary talked about a boy in their class who was known for wanting to become a scientist (“that guy loves science”). The private school girls also described a known “science person”:

Int: And do you any of you all want to be scientists when you grow up?
Girl 1: I think that this boy in our class named [name], I think he wants to be a scientist.
Girl 2: He’s really complicated.
Girl 1: Mr [name], he gave us a shortcut for this answer, and he [boy] goes for the most complex scientific proper maths ways, and so does his brother.

This was not unique—other groups also made reference to peers who were “known” as interested in pursuing science, suggesting that science is already operating here as a marked identity. This is irrespective of the claim that the children also made that anyone can do science if they want. Here the “real,” authentic science identity is distinctly embodied by particular individuals (notably “complicated” and “complex” individuals—see next section on “the boffin”), suggesting that while anyone can “do” science, only a few will really “be” scientists and that the identities of these children are popularly “known” from an early age.

The discourse of “natural interest” links closely with the idea of there being a “science person”—someone who is naturally interested in science and who has a “science mind.” The research of Mendick et al. (2009) with children and young people highlighted popular constructions of a “maths person” who has a “maths mind.” While at one level this construction might seem innocuous, it operates as a powerful embodied discourse that constructs a rigid division, akin to the distinction between “science people” and “nonscience people.” While the children in our study do not subscribe (yet!) to such distinctions, their instinctive use of a discourse of “natural interest” might be interpreted as signaling how their current simultaneous construction (of “anyone can do science if they try”) may become eclipsed in later years by the discourses of “science as natural interest” and “the science person.”

Mendick et al. (2009) argue that the power of the construction of the “maths person” is predicated upon its association with notions of “natural ability.” This obviously sits in an uneasy relationship with a discourse of excellence as achieved through effort, although as Mendick et al. note, the two are often voiced together:

There is a complex relationship between natural ability and hard work, with most people supporting both the idea that you can get better at maths through hard work and the idea that some people are naturally more able to do maths than others.

In other words, they argue that there is a recurrent contradiction between the notions of natural ability and improving through effort and “a recurrent opposition between being a hard worker and being naturally able” (Mendick et al., 2009).

The discourse of “science as natural interest” also links in with dominant constructions of educational achievement as configured through natural ability (Walkerdine, 1988, 1989, 1990; Skelton & Francis, 2008). As a wealth of research has demonstrated, within dominant educational and popular discourse the identity of the “ideal pupil” is popularly constructed as epitomized by “effortless brilliance” (which is configured as male), which

*Science Education*
is located oppositionally to “diligent” and “plodding” achievement (which is configured as female); e.g., see Francis and Skelton (2005). The prevalence of this binary has been noted internationally as characterizing many teachers’ talk. It has also been noted within science classrooms: for instance, boys in the physics classroom studied by Carlone (2004) in the United States, and in the U.K. classrooms studied by Warrington and Younger (2000), were described by their teachers as possessing a greater “natural ability” in science. In contrast, girls were constructed as diligent and hard working but lacking the flair and effortless brilliance of their male counterparts. The researchers noted that all these perceptions were irrespective of actual achievement (i.e., not all “brilliant” boys were achieving highly and even the highest achieving girls were described as owing their attainment to “hard work”). Against this powerful discursive backdrop, it is perhaps not surprising that many girls and young women come to see their identities as inconsistent with dominant constructions of the “real” or authentic scientist, whose identity is associated with “raw” (Carlone, 2004), “natural” talent, interest, and ability.

Indeed, Mendick (2006) details the considerable identity work undertaken by students in a Further Mathematics (an advanced-level upper mathematics) class to avoid identifying as being “good at maths.” She found that students tended to attribute their success in mathematics to their “doing” (diligence, working hard) as opposed to being attributable to “being” good at mathematics. This was particularly the case for girls. Mendick argues that being “good at maths” is “a position that few men and even fewer women can occupy comfortably . . . they persist in constructing the mathematician as something you are or are not ‘naturally’ ” (p. 216)

**Scientist as Boffin**

Closely related to the preceding themes of “science as hard” and “science as natural interest,” we identified the construction of “scientist as boffin.” “Boffin” is a colloquial term used in the United Kingdom, Australia, New Zealand, and South Africa, similar to the American notion of an “egghead”:

Boffins are “scientists, engineers, and other people who are stereotypically seen as engaged in technical or scientific research.” The word “boffin” (or “boff”—often as an insult) can also be used to refer to any particularly clever person. The closest American equivalent is “Egghead.” (Wikipedia, http://en.wikipedia.org/wiki/Boffin)

In U.K. schools, the term “boffin”/”boff” is used generically (it is not just restricted to science) to denote (and often ridicule) high achieving students who are associated with notions of “cleverness” (Francis, 2009). The science boffin is embodied by the popular and familiar stereotypical representation of the brilliant but eccentric scientist, epitomized by his “wild” hair and distinctly marked in racial, age, gender, and class terms as White, old, male, and middle class. In our research, Einstein was most often evoked to capture this representation.

Boy 1: When I hear science I usually think of this man with a big moustache and like bald here [points to own head] and like with hair all around his head, and then

Boy 2: Robert Einstein

Boy 1: Yeah, Robert Einstein. And he’s got a flask in his hand and he has this green liquid and he pours it into another bottle another flask that has red liquid and then all of a sudden—caboom!

*Science Education*
Boy 2: Chemicals
Girl 1: Like explosions like you know when you like [inaudible]
Int: You mix things up, yeah
Boy 3: He’s wearing glasses
Girl 2: Like goggles

(Roman Catholic Elementary, mixed)

Int: What makes someone good at science?
Boy 1: When they know a lot.
Int: When they know a lot? What about you, what were you going to say?
Boy 2: I was going to say the same.
Int: When they know a lot?
Boy 3: When they have big moustaches and they’re a scientist.

The notion of the scientist as a brilliant (if eccentric) genius has also been noted in popular stereotypes of mathematicians (Epstein, Mendick, & Moreau, 2010), who observed how often, within young people’s views, there is a conflation between being good at mathematics; masculinity; high intelligence; and middle/upper classness. Moreau et al. (in press) also found that 14/15-year-old school students differentiated between stereotypical representations of mathematicians (who are short-haired geniuses) and scientists, who have long, wild hair (“scientists have crazy hair”). Unsurprisingly, this image was not seen as an attractive or desirable identity by many students, especially not girls who wanted to look “beautiful” instead:

I wouldn’t want to be a scientist because I don’t want to find these like dead bodies and bones and . . . ugh! And then I wouldn’t like to have big grey frizzy hair . . . because all scientists seem to have these caps on like bald heads and they have like [inaudible] and I don’t want to look like that, I want to look beautiful. (Girl, Inner City Elementary)

Such findings chime with other studies, in which elementary and secondary school girls report enjoying science but cannot imagine themselves as scientists (e.g., Baker & Leary, 1995; Jenkins & Nelson, 2005.

We would hypothesize that the dominant popular association of “boffin”/egghead identity with science will be undesirable (and require negotiation) for any girls who are invested in the construction of conventional (heterosexual, gender-traditional) femininities, but racialized and classed discourses of femininity would suggest that this may be especially undesirable or problematic for particular groups of girls whose identities (e.g., as non-White and/or working class) are not typically associated with “boffin” identity. For instance, research demonstrates how popular working-class (especially White working class) discourses of femininity may not sit easily with notions of academic achievement (as compared, for instance, to middle-class discourses around the “blue-stockings”) and how some of these constructions draw particularly heavily on certain embodied practices around “glamor” (Archer, Halsall, & Hollingworth, 2007; Skeggs, 1997) and sexuality (Renold, 2005). This is not to say that middle-class girls do not experience tensions in balancing a “desirable” femininity with academic achievement (cf. Reay, 2001; Renold, 2005), but that they have comparatively more discursive resources available to them to navigate this identity dilemma, given the popularly perceived congruence between academic achievement and middle-class femininity. For many working-class girls, a science identity may seem unintelligible (Butler, 1990) and completely incompatible with the versions of femininity that they recognize as culturally desirable and acceptable. In other words, to imagine oneself
into a space of being, young people need to be able to “take up a science identity that can be recognized and accessed by others” (Calabrese Barton & Brickhouse, 2006, p. 224).

The interplay between discourses of femininity, sexuality, achievement, and science constitutes a space for analysis that we hope to pursue further as our study develops. Our conceptual starting point is that if high achievement and “effortless brilliance” tend to be constructed as masculine, then high-achieving girls are required to engage in a form of identity work that involves the negotiation of an acceptable form of femininity (see Francis, Skelton, & Read, 2009, in the context of high-achieving students in the United Kingdom). In the case of science, this is heightened further, due to dominant constructions of science as a masculine field. The ability for girls to navigate a successful (achieving) science identity will be overlaid further by social class and ethnic identities—being potentially slightly more congruent for middle-class girls (for whom dominant notions of “acceptable” academic femininity tend to be linked with the suppression of sexuality, Renold, 2005; Renold & Allan, 2006; Skelton & Francis, 2008). Ethnic identities will provide yet another crucial layer, or lens, for analysis. While Whiteness may be aligned more closely with the image of “the scientist” in popular discourse (and hence may be a potentially congruent identity discourse), evidence suggests that the perceived “respectability” and acceptability of a science identity may be constructed differently among ethnic collectivities (e.g., see Archer & Francis, 2007, in the case of the British Chinese). The interplay between race, class, and gender may mean that some families and collectivities may recognize and espouse versions of acceptable or respectable femininity which (for girls or young women at least) may render science as a more acceptable identity (for instance, due to its “status” and the associated discursive repression of sexuality).

Despite the potentially positive associations that might be expected to follow from being identified as highly intelligent by virtue of taking up a science identity, as Epstein et al. (2010) highlight in relation to mathematics, boffin identities reside dangerously close to “geek” (or nerd) identities—a stigmatized social/learner identity that many children seek to avoid. We would suggest that the children’s constructions of the scientist as boffin indicate that, as they get older, a science identity will come to operate as a pariah identity (Francis, 2009) within the classroom—only a few students will be willing to “risk” or embrace the identity due to the negative weight that it carries in popular identity terms. Its boffin associations and incongruence with popular/desirable forms of contemporary masculinity and femininity (especially working-class configurations) make it a potentially risky identity, being closely associated with markers of an “uncool” identity.

Francis et al. (2009) argue that if high-achieving pupils are to also be popular (and resist being positioned by their peers as boffins) they have to mobilize certain embodied capitals (notably physical attractiveness and fashion and or style) and conform to performances of dominant (conventional) gender identities (e.g., being sporty for boys and being “girly” and coquettish for girls). Brickhouse and Potter (2001) describe the case of Ruby, an African American girl in their longitudinal U.S. study who had to engage in sustained identity negotiations to balance her achievement and participation in a competitive computing program with an acceptable femininity. Ruby attempted to achieve this by balancing her “masculine” performances of achievement (and achievement in a traditionally male sphere) with her performances of hyperfemininity (e.g., doing modeling and cheerleading). This was not easy, as detailed by her “struggle to construct a livable identity in a competitive computing program in which she desires computing competence but does not desire other aspects of the central image of the computing program” (Brickhouse & Potter, 2001, p. 971). Thus, it seems likely that if an adolescent student is to embrace a science identity he or she must either inhabit the position of pariah (the socially derided “geek”) or possess the requisite embodied capitals to also convincingly perform dominant heteromasculinity/femininity.
The Defense of Science as Masculine: ("Fashion and Science Don’t Mix")

Drawing on the data from this study, we have argued thus far that taking up a science identity may be undesirable for many groups of young people but may become particularly problematic for girls (especially working-class girls) as they progress through compulsory (and by extension, we imagine, postcompulsory) education. In this final section, we wish to highlight how, in the case of girls’ scientific identities, boys do not play a silent or passive role in this process. This is reflective of how discourses are not external, objective structures (that exist “out there” in society) but are active—they are constantly taken up, resisted or embraced, and reworked. The exclusion of girls from a high-status (albeit contradictorily configured) identity and field such as science is part of the patriarchal dividend—a state of affairs from which boys or men may benefit more generally. In this respect, it was not surprising that we found evidence of some boys making their own active investments in reproducing and policing the boundary of science (arguing that it is or should be a male preserve). This is encapsulated in the following extract, in which a group of boys suggest that girls are not “naturally” into science because “fashion and science don’t mix.” The boys argued that boys are better at science, explaining that the scientists they know are all men (“cos my uncle’s a scientist and he’s a boy”; Newton, Einstein, and Edison were also cited). One of the boys also suggested that girls “have no confidence” in science, and this was due to their preoccupation with “their nails chipping when they’re doing the experiments.”

Boy 1: don’t think girls would make good scientists or like you know inventors and that, because they aren’t usually interested in science mostly. If a girl is yeah, they would become famous like . . . there might be a girl that invented something—is there?

Int: Mm.

Boy 2: Yeah yeah. They mostly care about fashion. If they put everything into it, but most girls these days care about fashion and their trousers (inaudible)

Int: Couldn’t [girls] care about fashion and science?

Boy 2: No they wouldn’t, because fashion and science don’t mix.

Boy 3: Your nails could get chipped.

Boy 1: I can add to that. Yeah, if they like . . . in science . . . cos most scientists wear glasses and girls these days care about fashion, and glasses aren’t in fashion.

(Inner City Elementary, boys)

The above comments were made by an all-male discussion group, and it was notable that none of the mixed-sex groups produced such accounts, presumably because the presence of girls would potentially have led to such views being challenged. But the above can also be read as part of these boys’ everyday performances of “doing boy.” This sort of “cartoon sexism” is not uncommon in all boy groups (e.g., see Archer 2002, 2003) and often tells us more about the ways in which boys discursively “jockey for position” with one another (e.g., by articulating controversial or socially “risky” views, or by adopting extreme or hegemonic viewpoints) than about their substantive views on gender equality. What is interesting here, however, is that science is recognized and deployed as a powerful resource for negotiating gendered subject positions. The boys all “know” that science is popularly configured as masculine and as high status and is hence something that, as boys, they would have a vested interest in claiming (as “for boys”). They recognize the ways in which science is popularly positioned as antithetical to femininity, and they are able to draw on dominant stereotypes around femininity to question its viability as an identity.
discourse for “real” girls (it is rendered acceptable only for unfashionable girls who do not “care” about their appearance, i.e., challenging conventional notions of popular or desirable femininity as compatible with science). This exchange thus alerts us to the issue that if, as educators, we wish to attract more girls into science then we will need to focus our attention as much on popular or dominant constructions and performances of masculinity (and the ways in which boys may defend and claim science—and hence challenge and resist such interventions) as we might femininity.

CONCLUSION

In this paper, we have identified and discussed a key dilemma for science education, namely that children can report enjoying science (e.g., they may find it fun, exciting, important, and interesting) but they may still see it as “not for me” and choose not to study it at a higher level (Jenkins & Nelson, 2005). We conducted our analysis of children’s discussion group talk through the lens of identity, noting how constructions of science and identity are circumscribed by social class, ethnicity, and gender. We detailed how, even at this young age when children are mostly enthusiastic about science, some aspects of a “science identity” are beginning to be ruled out as not only undesirable but even “unthinkable,” and other aspects are understood as possible or desirable only under certain identity conditions. In other words, beneath the broad brush general enthusiasm for science expressed by these children (independent of gender, ethnicity, and social class), we can excavate the germination of (gender, ethnic, class) distinctions that will come to be solidified in later years. Our analytical distinction between “doing” and “being” provided an entry point to understanding and explaining this disjuncture.

The children’s discursive demarcation between school science (as “safe”) and “real” or adult science (as “dangerous”) highlights a real dilemma for educators: reworking school science in a way that would be more attractive to hegemonic masculinity (assuming this is even possible) might increase the interest and engagement of some boys but would be undesirable in that it would alienate girls and other boys and, given the inherent tensions between “laddishness” and schooling, may well be unsuccessful even with its target group. The disjuncture we have identified between “doing” and “being” would also lead us to question the utility of such an approach. Indeed, Osborne and Dillon (2008) have argued, for instance, that what is required is a new vision of science education, not only of what we know and how we know, but also what kinds of careers science affords—both in science and from science—and why these careers are personally fulfilling, worthwhile, and rewarding.

We also suggested that subtle differences between children’s nature of engagement with out-of-school science also contain indicators of future distinctions (particularly classed distinctions) in terms of patterns of achievement and engagement in science. This suggests that a focus on reforming school science alone may not be sufficient if we are to broaden its appeal.

Finally, we would suggest that the content of the “being a scientist” construction (in terms of science as hard/brainy; science as natural interest; scientist as boffin) have enabled us to tease out the complex interplay of discourses of gender, sexuality, ethnicity, and social class within children’s everyday constructions of science. Our analyses lead us to identify a conundrum in that, in its present form, science appears to be constructed as “too feminized” for (many) boys and “too masculine” for (many) girls. This appears to constitute an impossible position—can science ever appeal to all constituencies as a viable identity? This may point to the need to work with multiple visions of science—a position that in itself suggests a need to disrupt dominant discourses around science and
the identity of the scientist. It also impels us to consider how we might bridge the gap between children and young people’s everyday identities (those that are experienced as desirable, authentic, and conveying status within their daily fields of interaction) and the identities and messages conveyed by school and “real” science. Our analyses suggest that intelligible gender identity performances within one field (e.g., home, peer culture) may be incompatible with others (e.g., science). In particular, a science identity as it is popularly configured appears unintelligible for some children and young people due to its dominant gendered, raced, and classed configuration.

Our analyses contribute to understanding the complex identity processes that may underlie the deep-seated, often trenchant, resistance that many interventions, designed to increase engagement and uptake of science among young people, have encountered. While many of these interventions have been carefully and thoughtfully designed by a range of appropriate experts and practitioners, evaluative evidence indicates that even the “best” interventions may still be resisted by pupils and/or enjoyed by those involved but make little or no difference to pupils continuing with science (e.g., see Carlone, 2004; Solomon, 1997). It is from this platform that we hope to be able to move forward to identifying how we might be able to interrupt dominant identity patterns of (dis)identification in relation to science in the future.

REFERENCES


Science Education


Kitzinger, J. (1994). The methodology of focus groups: The importance of interaction between research participants. Sociology of Health & Illness, 16(1), 103–121.


Monica Edwards was frustrated.

As a teacher in an urban elementary school, Edwards faced a class that was largely African American and Latino: she was neither. She often felt that she wasn’t effectively reaching them, and she was beginning to get discouraged. (Monica Edwards isn’t her real name. She’s a real teacher who told me her story privately.)

After hearing a colleague briefly mention her success in using culturally relevant instructional strategies, Edwards decided to try her hand at the same. She bought a commercial CD called Multiplication Rap, which promised to teach mathematics based on repetition and rhyme, hand-clapping and a hip-hop musical style. She was sure the CD would appeal to her students’ interest in the rap music genre.

In the classroom, however, things didn’t go quite as planned. Students focused on the music itself, paying little attention to the math objectives. Several were unimpressed with the CD, and commented on the poor audio quality and amateurish lyrics. Except for the musical debate, nothing much happened. The failure rate on Edwards’ weekly exam did not change.

Sadly, Edwards’ experience is not uncommon. Many teachers have a cursory understanding of culturally relevant pedagogy, and a desire to see it succeed in their classrooms. The problem is that in many cases, teachers have only a cursory understanding, and their efforts to bridge the cultural gap often fall short.

“Culturally relevant pedagogy” is a term that describes effective teaching in culturally diverse classrooms. It can be a daunting idea to understand and implement. Yet even when people do not know the term, they tend to appreciate culturally relevant pedagogy when they see it.

Think of the film Stand and Deliver, in which Edward James Olmos, as teacher Jaime Escalante, teaches his students about negative numbers using the example of digging and filling holes in the sand on the California beach. He tells his mostly Latino class that the Mayan civilization independently invented the concept of zero. When the students begin to catch on, the audience is inspired by this moment of epiphany.

Most people understand intuitively that this type of teaching engages and motivates students. Teachers want to be a Jaime Escalante for their own students — and they leap at the chance to try new techniques or tools designed to bridge a cultural gap.
Often, these well-meaning educators assume that culturally relevant pedagogy means simply acknowledging ethnic holidays, including popular culture in the curriculum or adopting colloquial speech. And many are afraid to take it farther than that. Why? Largely because they believe the following myths:

- Only teachers of color can be culturally relevant.
- Culturally relevant pedagogy is not appropriate for white students.
- Caring teachers of diverse students have no classroom management skills.
- The purpose of culturally relevant pedagogy is to help diverse students “feel good” about themselves.
- Culturally relevant teachers attend to learning styles by addressing African American male students’ need for kinesthetic activities or by allowing Asian American students to work alone.

These myths and misperceptions often result in awkward classroom moments, ineffective instructional practices and counterproductive teacher-student and teacher-parent relationships.

Let’s tackle the biggest myth first. Culturally relevant teaching may indeed boost the self-esteem of your students, but that’s not the main reason you should adopt it. You should take a culturally relevant approach because it will maximize student learning.

A culturally relevant pedagogy builds on the premise that learning may differ across cultures and teachers can enhance students’ success by acquiring knowledge of their cultural backgrounds and translating this knowledge into instructional practice.

Culturally relevant pedagogy has theoretical roots in the notion that learning is a socially mediated process and related to students’ cultural experiences. Culture is an important survival strategy that is passed down from one generation to another through the processes of enculturalization and socialization, a type of roadmap that guides and shapes behavior. If new information is not relevant to those frameworks of culture and cognition, people will never remember it. If the information is relevant, they will never forget it.

**The March To the Mailbox**

Let me give you an example to show how culturally relevant pedagogy works, and why it works for all students.

A teacher in a low-income school once told me about her struggle with that age-old task: teaching students to write a business letter. Her textbook offered what sounded like some pretty good advice for making this task relevant to students. Bring a toy catalog to class, it said, and let students write letters placing an order for a Game Boy or other item.

The teacher tried to picture this working with her students. Most of them couldn’t afford a Game Boy. And who orders catalog items with a business letter these days? She decided that this exercise, so seemingly good in theory, would seem completely pointless to her students.

So she found another, more appropriate task. She told her students they were going to write letters to the mayor, asking for changes that would make life better in their neighborhood. She told students not to rely solely on their own perspectives: they should go into the community and ask relatives, neighbors and
church leaders about the problems in the community. The students did their research — learning about their community and strengthening their bonds with family — and wrote their letters. The teacher held a “march to the mailbox,” mailing their letters with great ceremony. And not long afterward, the mayor was on the phone with the principal, asking when he could visit the class and address their concerns in person.

The cultural norms and behaviors of schools are based on a very specific set of mainstream assumptions. When there is a cultural mismatch or cultural incompatibility between students and their school, certain negative outcomes might occur, such as miscommunication; confrontations among the student, the teacher, and the home; hostility; alienation; diminished self-esteem; and possibly school failure.

In the case above, someone assumed that all students had the means to envision themselves ordering a Game Boy. Perhaps just as important, it assumed that young people are interested only in acquiring toys — that they had no interests or lives outside of getting and spending. The teacher’s solution to this problem was truly culturally relevant because it drew on the students’ resources and experiences. It worked extremely well for this group of students, who got to see their own knowledge, and that of their community, honored in the classroom. But clearly it would have worked well even in other communities.

What could Monica Edwards have done differently? Culturally relevant teaching requires the teacher to possess a thorough knowledge of the content and employ multiple representations of knowledge that use students’ lived experiences to connect new knowledge to home, community, and global settings.

What do we mean multiple representations? Teachers need to find pertinent examples in students’ experience; they need to compare and contrast new concepts with concepts students already know; they need to bridge the gap between the known (students’ personal cultural knowledge) and the unknown (materials and concepts to be mastered).

In one of my texts, Culturally Responsive Lesson Planning, my colleagues and I present culturally relevant and transformative lesson units in four subject areas that are aligned with content area standards. Examples include:

- teaching weather and other scientific concepts by first helping students to understand the connections between their culture and weather as portrayed in myths, folklore, and family sayings;

- teaching social studies by helping students in urban communities to analyze and report voting patterns in their neighborhood and execute a voter education project.

There is a widespread myth that teachers who care about a culturally relevant classroom are not the ones who care about rigor. In reality, culturally relevant pedagogy is perfectly aligned with high standards in the content areas. Just look at the standards of the National Council for Teaching of Mathematics. The first of NCTM’s principles and standards is the Equity Principle, which states: “Excellence in mathematics education requires equity — high expectations and strong support for all students.”

Culturally relevant teaching isn’t about lowering those “high expectations.” It’s about providing strong supports by approaching effective instruction through a cultural lens. I believe that many diverse students fail in schools not because their teachers don’t know their content, but because their teachers haven’t made the connections between the content and their students’ existing mental schemes, prior knowledge and cultural perspectives. In helping learners make sense of new concepts and ideas, culturally relevant teachers create learning opportunities in which students’ voices emerge and knowledge and meaning are constructed from the students’ perspectives.
Monica Edwards, the teacher in the opening of this story, is a good teacher. She wanted her students to learn, and she correctly identified the student/school cultural gap as a possible reason for their lack of learning gains. She and her colleagues deserve support in the form of professional development that helps them achieve their goals. Not superficial, one-day teacher workshops on diversity or multiculturalism: these often do more to maintain stereotypes and biases about culturally diverse students and their families than to change them. Not a focus on international festivals and once-a-year programs honoring Black History Month or Cinco de Mayo. Teachers need to be encouraged to question the curriculum and the pedagogy.

**Educated Guesses**

Culturally relevant teachers form caring relationships with their students.

I remember an incident that occurred while I was observing a preservice teacher at work in a mostly-black elementary school in the South. The topic was classification: students were supposed to show ability to sort out like and unlike objects and consonant sounds. When the teacher showed students a photograph of a wrinkly, cabbage-like vegetable, she expected them to identify it as kale. Students were stumped, though some guessed that it was collard greens. Later the teacher showed the students a picture of broccoli, which the students also could not identify. (Not everybody cooks broccoli. I grew up in Alabama, and I never saw broccoli on a plate until I was in college.) The teacher couldn’t hide her shock that the students didn’t recognize this vegetable: the students began to suspect that they were being lured into a game they couldn’t win. Soon the students were acting up, and the teacher, upset, was storming out of the room.

I searched my mind for something to do. I recalled hearing students talking, before class, about the cars they’d seen in the school parking lot that morning. I asked them if they could name the various types of cars they’d seen. As it turned out, they had quite an extensive knowledge of brands and makes of cars. We classified the information we collected, sorting the cars into vehicles driven by first-grade teachers, vehicles driven by second-grade teachers, and so on. We even did a little geography, with students using a map to point out where various cars came from. Students had some trouble finding Sweden, but they knew Volvos came from there. We talked about what a hypothesis was — an educated guess — and as homework, I asked them to look over their data about cars and make a hypothesis about the difference between principals and new teachers. The next day, many students hypothesized, based on the cars in the parking lot, that principals make more money than teachers.

You could say I got lucky in this situation. But if you have a true, caring relationship with your students, you don’t have to be lucky. You will know what their interests are, what information they relate to. Even in an abstract discipline like mathematics, relationships with students matter. When you’re talking about distances, it certainly helps to be able to say, “I heard you talking about your cousin Miguel. How far do you think you go to visit him?”

Culturally relevant teachers recognize that they do not instruct culturally homogenized, generic students in generic school settings. Teachers armed with a repertoire of generic teaching skills often find themselves ineffective and ill-prepared when faced with a classroom of culturally diverse students.

Teachers need to re-envision their roles in schools. Culturally relevant teachers are systemic reformers, members of caring communities, reflective practitioners and researchers, pedagogical content specialists and antiracist educators.
As systemic reformers, culturally relevant teachers must lead, not simply respond to, the call for whole school reform. Educating and mentoring peers is part of that. All teachers, not just novices, benefit from the expertise and guidance of master teachers who observe their classes and coach them on a regular basis. In addition, teachers need release time to observe master teachers in their classes and periods for conferencing and planning.

They also need to make time to reflect on their classroom experiences. Reflection enables teachers to examine the interplay of context and culture as well as their own behaviors, talents and preferences. Reflective teachers are inquirers who examine their actions, instructional goals, methods and materials in reference to their students’ cultural experiences and preferred learning environments. The culturally relevant teacher probes the school, community and home environments searching for insights into diverse students’ abilities, preferences and motivations. This type of reflection assists teachers in confronting their misunderstandings, prejudices and beliefs about race that impede the development of caring classroom climates, positive relationships with their students and families, and ultimately their students’ academic success.

Thinking of culturally relevant teachers as action researchers extends another important component of the reflection process. Action research is inquiry conducted by teachers for teachers for the purpose of higher student achievement. Action research requires teachers to identify an area of concern, develop a plan for improvement, implement the plan, observe its effects, and reflect on the procedures and consequences.

Finally, student achievement is not the only purpose of a culturally relevant pedagogy. Culturally relevant teachers must also assist students to change the society, not simply to exist or survive in it. For some teachers, this can be very challenging. When teachers promote justice they directly confront inequities in society such as racism, sexism and classism. Far too many teachers appear to be not only colorblind, but also unable or unwilling to see, hear or speak about instances of individual or institutional racism in their personal and professional lives.
Culturally Relevant Teaching in Science Classrooms: Addressing Academic Achievement, Cultural Competence, and Critical Consciousness

Gloria Boutte
University of South Carolina
U. S. A.

Charlease Kelly-Jackson
Claflin University
U. S. A.

George Lee Johnson
South Carolina State University
U. S. A.

This article provides classroom examples and commentaries for extending and deepening culturally relevant science teaching efforts in classrooms. It examines instructional efforts used by one of the authors with high school and university students. Together, the three authors rethink and reconsider several aspects against a culturally relevant pedagogical backdrop. The commentary points out considerations for focusing on student achievement, cultural competence, and critical and sociopolitical consciousness. The necessity and difficulty of centering culture, equity, and power relations are emphasized.

The Sociopolitical Context
Culturally Relevant Pedagogy (CRP)
Culturally Relevant Science Instruction
CRP Example 1: Cell Analogies Collage
CRP Example 2: Extracting DNA Activities
CRP Example 3: Integumentary System Unit
Problematizing Science as “Factual” and Uncovering Scientific Racism
Conclusion
Note
References
Appendix

The Sociopolitical Context

In light of challenges faced by the increasing racial and ethnic diversity among students in pre-K-12 schools in the U.S. and the accompanying decline in diversity among the population of teachers, culturally relevant teaching has become a promising and compelling educational and ethical consideration and
movement (McKinley, Jones, & Castagno, 2008). However, conversations regarding culturally relevant teaching typically occur in academic circles and have been sluggish in reaching practitioners. In our professional development sessions with practitioners, science and mathematics teachers frequently misperceive culturally relevant teaching to be appropriate for language arts, social studies, and fine arts, but not for the so-called “hard sciences.” Responding to the need to make culturally relevant science discourse accessible to practitioners, this article provides three examples of a science teacher’s efforts and a commentary on how to go beyond superficial efforts and attain more authentic culturally relevant teaching.

During the last few decades, a considerable number of mathematics educators have addressed ethnomathematics and culturally relevant mathematics (e.g., Berry, 2008; Davis & Martin, 2008; Gutstein, Lipman, Hernandez, & de los Reyes, 1997; Joseph, 1987; Ladson-Billings, 1997; Lynn, 2006; Martin, 2007; Matthews, 2003; Rousseau & Tate, 2003; Tate, 1995). Likewise, there has been a shift from the notion that science education is value- and culture-free, and ethnoscience is also on the rise (Kahle, Meece, & Scantlebury, 2000; Lee & Buxton, 2008; Lee & Luykx, 2007; Luykx & Lee, 2007; Sadler, Amirshokoohi, Kazempour, & Allspaw, 2006; Roth & Tobin, 2007).

Based on our experiences and perusal of literature, there are few classroom models of culturally relevant science (and mathematics) teaching. The lack of translation of cultural aspects of science to the classroom may be explained in part by the low priority placed on science in schools (Wood & Lewthwaite, 2008). Despite academic science literature to the contrary, the narrow definition of science education as the teaching of “facts” is quite common in schools, coupled with a general absence of instruction and curriculum regarding the ways in which culturally and linguistically diverse students’ knowledge and experiences relate to science disciplines (Emdin, 2010; Lee & Luykx, 2005). As is typical in the academy, there is much theoretical talk about culturally relevant pedagogy, but few explicit classroom examples which help teachers envision possibilities and gain insight on ways to deepen their understanding of the complexities involved in the process. As one science educator recently queried, so how does culturally relevant teaching look in an actual classroom?

In this article, we share three examples of initial ventures by one of the authors’ into using culturally relevant science teaching as a viable possibility for bridging the distances between school instruction and ways of knowing and realities within the homes and communities of culturally diverse students. We focus specifically on African American students, but the general tenets can be extrapolated for other cultural groups as well. As African American professors, we find that many educators do not tend to think of African American students in cultural terms (Ladson-Billings, 2000). However, we recognize African Americans as a distinct cultural group which shares collective experiences and lived realities that extend across socioeconomic and geographical boundaries (Boykin, 1994; King, 2005; Ladson-Billings, 1999, 2000). While African
Americans hold multiple identities and are not monolithic, we also share collective memories, history, and contemporary realities that cannot be overlooked or disregarded.

Drawing from Martin’s (2007) framework, three types of knowledge/skills are needed to teach African American students effectively: 1) deep content knowledge; 2) strong pedagogical content knowledge; and 3) strong culturally relevant pedagogy. The first two are frequently discussed and are not the focus of this article. Sharing concrete examples of culturally relevant science teaching is both a strength and caveat of this article. On the one hand, sample classroom examples can illuminate the process for teachers and help translate theory into practice. On the other hand, readers may overlook the complexities of the process and reduce it to “recipes” or activities. Our intent is to suggest general tenets for the process of changing the structure, assumptions, and nature of science teaching. Like the examples presented, it is not unusual for practitioners to begin the process by adding multicultural information and contributions of famous people into the existing curriculum. This article provides insights and guidance for practitioners who wish to deepen their efforts in using a culturally relevant pedagogical framework. We conclude that without centering issues of power, equity, and culture, efforts will remain superficial and will not likely address the intended long-term goals of reducing structural inequities in school and society (Castagno, 2009).

**Culturally Relevant Pedagogy (CRP)**

*Culturally relevant pedagogy* “empowers students intellectually, socially, emotionally, and politically by using cultural referents to impart knowledge, skills, and attitudes” (Ladson-Billings, 1994, p. 18). Teachers who practice culturally relevant teaching use cultural knowledge, prior experiences, frames of reference, and performance styles of culturally and linguistically diverse (CLD) students to make learning encounters more relevant to and effective for them (Bonner, 2009; Gay, 2000). Culturally relevant teaching focuses on: 1) academic excellence that is not based on cultural deficit models of school failure; 2) cultural competence which locates excellence within the context of the students’ community and cultural identities; and 3) critical consciousness which challenges inequitable school and societal structures (Ladson-Billings, 2002). While many erroneously think that the main focus of culturally relevant teaching is solely on affirmation of CLD students, it should be stressed that academic achievement is a central goal of culturally relevant teaching. Unquestioningly, as students become culturally competent, their cultures are indeed affirmed (as is currently the norm for White students in most schools). However, culturally relevant teaching must result in student learning. Unlike most classrooms, culturally relevant classrooms do not devalue the cultural knowledge and worldviews of students of color. Students’ learning is placed in a relevant context while students also become more proficient at understanding their cultures. The critical consciousness/sociopolitical dimension of culturally relevant pedagogy offers a
critique to the notion that content knowledge and content pedagogical knowledge are neutral and “objective.” The cultural fingerprints of content knowledge and instruction are made evident, critiqued, deconstructed, and reconstructed. Culturally relevant pedagogy (CRP) assumes that the way teachers teach profoundly impacts students’ perceptions of the content of the curriculum (Ladson-Billings, 1994). Culturally relevant pedagogy can be eloquently summarized by Ellison (2008),

“If you can show me how I can cling to that which is real to me, while teaching me a way into the larger society, then I will not only drop my defenses and my hostility, but I will sing your praises and help you to make the desert bear fruit [no pagination].

Culturally contextualized instruction holds the most promise for the academic success not only for students of color but for White students as well (Pritchy-Smith, 1998). In order to develop exemplary abilities in any content area, teachers must be able to link instruction to what is already familiar to their students. This may require teachers to engage in micro-ethnographies of sorts to develop an in-depth understanding of children’s communities, families, leisure activities, and worldviews. Culturally relevant teaching includes not only learning about the lives of CLD students, but learning from them as well. Information learned about and from students can be used to transform classrooms into culturally relevant contexts.

Culturally Relevant Science Instruction

Culturally relevant teaching is congruent with the national science education standards (National Science Teachers Association, 2003) definition of scientific inquiry: “the diverse ways in which scientists study the natural world and propose explanations based on the evidence derived from their work” (National Research Council, 2000, p. 23). However, a key distinction between scientific inquiry and culturally relevant science is the degree of emphasis on sociopolitical and critical analyses. In the examples that we share, we explicitly make the point that conventional instruction, curriculum, and assessment will need to be rethought and reframed in culturally relevant classrooms.

Colombian ethnolinguist, Mario Edgar Hoyos, distinguishes between curriculum and curricula (M. E. Hoyos, personal communication, September 24, 2007). He defines curriculum as the “typical Eurocentric course of study and content that is thinly disguised as universal and classic. It is a universalistic, one-size-fits-all model” that is typically used in classrooms. Contrastingly, curricula are described as powerful and multiple possibilities, adaptations, modifications, and deconstructions of the former which allow for a broader, comprehensive, and more varied version of the former curriculum. In the case of the author’s (CKJ) classroom, centering African and African American culture moves the narrowly defined curriculum to the status of curricula which is more inclusive. Like other scholars studying culturally relevant science (McKinley, Jones, & Castagno,
CKJ wanted to know, “How can science teachers enable all students to study a Western scientific way of knowing and at the same time respect and access the ideas, beliefs, and values of non-Western cultures?” (p. 743). Her intent was not to supplant the “science curriculum.” Rather, she sought to add multiple perspectives, critiques, and counter-stories which required attention to particular cultural contexts. Consider the three examples below, followed by a tri-vocal commentary by all three authors, including CKJ.

CRP Example 1: Cell Analogies Collage

CKJ’s interest in learning how to teach science more effectively to African American students led her to venture into culturally relevant teaching. Her openness to feedback indicates that she views herself as a learner who recognizes that becoming a culturally relevant teacher is an ongoing journey. As will become evident, her first efforts focused primarily on engaging students (with little or no emphasis on critical and sociopolitical consciousness). With an unspoken and commonly espoused goal of increasing the number of African American scientists, she sought to increase students’ critical thinking skills by demonstrating the interdisciplinary nature of science and defying the notion that science learning is boring and irrelevant to real life settings. She also wanted students to learn scientific terminology which could be used in dialogue with other scientists and in understanding science content.

Balancing her expectation for students to learn the course’s content with the realization that students did not find the mundane memorization of science vocabulary engaging, she reasoned that the study of cells would lend itself to interesting and relevant activities. CKJ found and adapted a cell analogies collage from AccessExcellence.org. The activity challenges students to make original analogies between cell structures and everyday objects and experiences.

To learn the chapter’s vocabulary words, students were asked to use personal references to develop analogies. CKJ spent time explaining analogies and giving examples (e.g., “The nucleus is like a brain because it controls and coordinates the activities of the whole cell in the same way the brain controls and coordinates activities of the body”). Students had to select at least 10 words from the chapter’s vocabulary list. At first her students showed little enthusiasm, but when they were able to bring their own interpretations, they became invigorated. They found magazine and newspaper pictures of everyday objects that had personal or cultural references that also had a similar function (or use) as each cell structure or organelle. Students used themes such as: 1) Let the Cells Say Amen (See Figure 1 and Table 1 in the Appendix); 2) What’s a Cell to a Cello?; 3) CEO and Cells; and 4) Willy Wonka and the Chocolate Factory. This activity implicitly and explicitly taught students the strategy of inventorying their interests and passions and relating it to what they were learning. In many ways, it validated the students’ worldviews and experiences, and they began to see science as less remote and the terminology as less convoluted.
In terms of outcomes, CKJ’s efforts helped improve student achievement, engagement, and interest. To hear students who had historically experienced little success in science exclaim their interest in taking other coursework was its own reward. Even more importantly, CKJ has noted that her efforts to engage students culturally and actively over the past four years have resulted in increased vocabulary scores and critical reasoning. For example, students’ test scores from this chapter ranged from 75-90% instead of the typical 60-85% when analogies were not used as an instructional strategy.

**Commentary on CKJ’s Cell Collage Activity**

Viewing the cell collage activity through the lens of the three dimensions of culturally relevant teaching (academic achievement, cultural competence, and critical consciousness), this activity produced mixed results. Academically, according to the records, students increased their passing rates on the vocabulary tests and are now more likely to integrate the vocabulary into their discussions and to understand scientific terminology. Yet, this is a very cursory level of achievement, and we do not want to leave the impression that culturally relevant teaching can be reduced to a bag of pedagogical tricks or one-time activities. All of us agree that an isolated activity cannot meet the larger goal of reversing students’ unfavorable view of science or increasing the likelihood of pursuing careers in science. The activity can serve as a rudimentary introduction to the notion that students can view concepts through their own cultural and personal lenses. Yet, this notion has to be probed through ongoing dialogic exchanges and opportunities to **read** and **act** on their lived experiences and worlds (Freire, 1970/1999). Students can explore who they are and what they
already know and how this applies to science in their personal spaces. Importantly, they will need opportunities to examine whose ideologies, knowledge, and worldviews are represented in the content and standards and whose are not. We will discuss this later after examining all three activities. While CKJ does a series of interesting and engaging activities in her classroom, they are loosely connected and would benefit from a cohesive, culturally relevant pedagogical framework which extends beyond definitions of academic achievement that are narrowly defined by mastery of the chapter's vocabulary.

So what about increasing the students’ cultural competence? Many African American students have had little or no exposure to information regarding scientists in the African diaspora. Whenever possible, CKJ provides powerful counter-narratives by using scientists of color (and females) so that students understand that science is not the purview of White men and also learn of strong science legacies among people of the African diaspora. A caveat is that cultural information presented should not be fragmented, presented on the periphery of the unit, or glossed over (Boutte, 1999). A good place to start is to explore scientific funds of knowledge in students’ own communities and spaces.

Discussion on cells can include the work of scientists like Dr. Ernest Just (Black Inventor, 2010; Hayden, 1970) whose work has not been amplified in most science books. Dr. Just sought to understand the world of the cell and sought to find "truth" using scientific methods and inquiry, challenging the theories of leading biologists of the 19th and 20th centuries. His scholarship contributed to scientific understanding of the process of artificial parthenogenesis and the physiology of cell development.

Culturally relevant pedagogy should not be narrowly defined as teaching only within the classroom setting, but should keep larger global perspectives and relevance to real world events as important considerations. Students who are faced with daily inequities are likely to identify Dr. Just’s experiences with racism and prejudice which ultimately led him to leave the United States and study in Europe in 1930. Comparisons and contrasts between various eras can also be discussed.

Dialogue regarding the different epistemological stances and the idea of “truth” can be critically explored. Doing so will require CKJ and other science educators to suspend the typical covering of topics to the uncovering of multiple perspectives. Yet, given the realities of classrooms, educators often fear that dialogues of interrelated issues not included in the standards will detract from student learning. In CKJ’s case, we can see that this was not the case and the academic outcomes of students were increased. More importantly, students actually liked CKJ’s classes and enjoyed learning about science.

As CKJ continues to develop her culturally relevant pedagogical skills, she can begin to help students increase their sense of agency as scientists. This can lead to inquiry efforts which address ethnoscientific problems in their communities and in the world, such as investigating the relationship of zinc levels and prostate cancer in African American males. CKJ may also consider using
hip hop pedagogy to teach science concepts as well as to critique scientific racism (Emdin, 2008).

**CRP Example 2: Extracting DNA Activities**

This series of activities was done with a group of African American high school students as part of a summer program designed to increase students’ awareness and interest in science-related disciplines and careers. The DNA extraction activity introduces students to various biological techniques. The activity integrated technology by having students visit the *Extracting DNA-Virtual Lab* (http://learn.genetics.utah.edu/content/labs/extraction/). The website provides students with a general idea of the process of extraction and its importance in biotechnology. Students followed links from the virtual lab to: *Extracting DNA from Anything* http://learn.genetics.utah.edu/content/labs/extraction/howto/. This activity was completed in class using various items such as chicken liver, strawberries, green split peas, and/or broccoli. Because most of the students were familiar with Crime Scene Investigation (CSI) television shows (e.g., *CSI-Miami, CSI-Las Vegas, and CSI-New York*), the idea of studying DNA biotechniques connected to their lives on some level. The shows allowed students to see how practical applications of DNA technology are used in our daily lives, from medical applications to forensic evidence. Additionally, students are familiar with talk shows such as *Maury*, which use DNA samples to determine paternity. This prior knowledge is useful in introducing students to the concept of ABO and Rh blood typing, invaluable tools in the fields of medicine and criminology.

For this activity, students tested four synthetic blood samples to identify the ABO and Rh blood types (see Figure 2). This activity introduced students to different blood types and how blood types are inherited. To reinforce students’ knowledge and to show cultural relevance, students identified and researched a selected blood disorder or condition (i.e., thrombosis and sickle cell). Engaging in scientific inquiry, the product of this assignment was a PowerPoint Presentation® which included: 1) causes; 2) diagnosis; 3) symptoms and complications; 4) data and statistics with a special focus on how it relates to African American populations; 5) tips for healthy living (again with a focus on the cultural relevance); and 6) the cost to society.

Figure 2. Students working on DNA samples provide a counternarrative to dominant imagery of White and male scientists.
Commentary on DNA Activities

Typical for initial ventures into culturally relevant teaching, an underlying subtext of the activity is for students to have “fun” and to be actively engaged. Some aspects of all three dimensions of CRP are evident but can be prodded.

This unit yields itself to the possibility of investigating genealogy studies that are being conducted by The National Geographic (2010) researchers and others who collect mitochondrial DNA and/or Y chromosomes. This can lead to very complex dialogues of genetics and history (e.g., how African Americans genealogies were affected by the trans-Atlantic slave trade and related ethical issues). Opening up such possibilities could lead young scientists (students) to pursue efforts which may be useful one day in providing African Americans with more information about their African lineage which was systematically destroyed during the slave trade.

A critique of Nobel Prize winner James Watson’s scientific work in light of his recent racist statements about Africans and Blacks being intellectually inferior (Boston Globe, 2007) could also be reexamined regarding the role that his beliefs may have played in research questions and conclusions. A dialogue on the topic helps make “scientists” less remote and also allows for examination of the relationship to research, questions posed, methods used, and biases. Seeing science as a human and cultural construction is key.

Charles Drew’s (Black Inventor, 2010; Lonesome & Huggins, 1990; Love & Franklin, 1997; Whitehurst, 2001) discoveries relating to the preservation of blood could serve as a counternarrative to discussing only White scientists. By separating the liquid red blood cells from the near solid plasma and freezing the two separately, Drew found that blood could be preserved and reconstituted at a later date. His system for the storing of blood plasma (blood bank) revolutionized the medical profession. He also established the American Red Cross blood bank, of which he was the first director, and he organized the world’s first blood bank drive, nicknamed “Blood for Britain.”

Sociopolitically, students can discuss the controversy surrounding Dr. Drew’s death. While driving to a science convention, he fell asleep and was seriously injured in rural North Carolina. In 1950, in the South, Dr. Drew was not admitted to an “all-White” hospital. Students can research the details of his death to determine the role that racism played. Some sources indicate that Dr. Drew needed a transfusion and was denied one; others disagree and said that he was not admitted to the White hospital, but was admitted to a “mixed-race” medical facility (Black Inventor/Drew, 2010). Dialogue, inquiry, and critical analyses on this topic position students as teachers/learners, which is the hallmark of culturally relevant science teaching. It also connects science to other disciplines such as history in this case and can propel students to take reflective action to address global problems in their communities and in society.
CPR Example 3: Integumentary System Unit

CKJ was able to see numerous possibilities for making the study of the integumentary system accessible to her university freshmen biology students. Given the sociopolitical nature of skin color, studying the integumentary system lends itself to a discussion of melanin (different levels of melanin by racial groups, skin tones, and benefits).

Since science is conceived as a socially and culturally constructed discipline, the inclusion of non-Western, indigenous, or other racial/ethnic traditions of knowing is important in culturally relevant science classrooms (Lee & Buxton, 2008). For example, CKJ’s discussion of skin and hair led to the discussion of Madame C. J. Walker’s (2010) development of Black hair products as well as the politics of Black hair. Chemical names of specific hair dressings, the impact that chemicals have on hair, as well as the safety and potential dangers of inadequate testing can be included. Even in racially integrated classes, through scientific inquiry students can examine their own personal hair/skin care products including testing, marketing, and ingredients for different types of skin and hair. While African American students can certainly serve as experts and informants on Black hair, educators will also need to spend some time studying Black hair in order to present information in a culturally informed manner.

It is important to note that in culturally relevant classrooms, conventional methods and assessments may be used when appropriate. For example, CKJ consulted the following website, and students tackled mini and mega quizzes on the topic: http://www.zoology.ubc.ca/~biomania/tutorial/skin/outline.htm. In this example, not only did this unit allow students to understand the basics of the integumentary system as one of our body’s systems, but they were able to connect the concepts to their daily living experiences and worldviews as well.

Many students were excited to learn more about Madame C. J. Walker (Altman, 1997) and realized that she played a role in their learning about science and science ethics. Most of the students surmised that Ms. Walker tested her products either on herself or family and friends and understood that her products were not tested to the extent products are tested today. The healthy discourse students had about product testing was refreshing, especially as they discussed their homemade hair/skin care products. In the end, students had a better understanding about skin and hair and the ethics and safety of product testing. They also were able to see how culture is related to modern day science, which was the underlining goal of the unit.
Commentary on Integumentary System

As in the first two activities, CKJ uses the textbook curriculum as the main source of ideas so that she can address the course’s objectives. Yet, as she thinks about Hoya’s conception of curricula, she understands that the unit can be revisioned based on students’ interests. At some point, CKJ may allow students to peruse the syllabus and textbook to determine particular areas of interest that they can engage in in-depth study. Small group inquiries into subjects may help students start to transform the view of science as a pre-set and non-dynamic subject. Allowing them to engage in “scientific processes” (not necessarily standard processes) will be an important part of capturing students’ voices and promoting critical consciousness. Here students can learn that many worldviews can and do co-exist. That is, they can come to understand that the textbook is one of many ways of knowing and that theirs may be another epistemology. Hence, they can become proficient in the “mandated” way of knowing alongside their cultural ideas, beliefs, and values (McKinley, Jones, & Castagno, 2008). From a critical point of view, contradictions between various epistemologies do not have to be reconciled. The following section suggests sample topics that may stimulate provocative dialogue and research by students and teachers. The topics are difficult and educators should be willing to position themselves as learners since addressing many of the issues will require consulting several sources and a willingness to accept non-resolution as a possibility for future study.

Problematicizing Science as “Factual” and Uncovering Scientific Racism

Probably the most difficult and surprising revelation for teachers and teacher educators who do this culturally relevant pedagogical (CRP) work is that they have to move beyond the typical neutral, apolitical stance in science and actively address oppression. This dimension is more than many teachers bargain for or are ready to address. Yet, without doing so, hegemonic principles and Eurocentric knowledge and ways of knowing are unintentionally privileged and reinforced.

In culturally relevant science classrooms, the assumption is that science involves inquiring into one’s own world. Hence, science content is not decontextualized from students’ and teachers’ everyday experiences. Overall, CKJ’s activities and engagements sought to tap into students’ interests; however, a key part of culturally relevant pedagogy (CRP) is addressing power relations. Because science, like other subjects, is cultural (Lee & Buxton, 2008), inevitably the way that we think about science in the United States reinforces existing power relations in society. That is, Western and European knowledge is privileged in textbooks and classrooms (Barton, Ermer, Burkett, & Osborne, 2003; Davis & Martin, 2008; Ryan, 2008). This CRP framework lends itself to
potentially interesting discussions and inquiries in classrooms regarding why the worldviews of some groups are marginalized and devalued. It gives educators a chance to reexamine science content and to problematize the widespread Eurocentric bias in the production and evaluation of scientific knowledge (Davis & Martin, 2008; Gould, 1981; Joseph, 1987). Difficult sociopolitical concepts like scientific racism can be explored, and students and teachers can begin to uncover inaccurate and incomplete information in the science literature.

“Scientific racism can be defined as the use of scientific methods to support and validate racist beliefs about African Americans and other groups’ [sic] based on the existence and significance of racial categories that form a hierarchy of races that support political and ideological positions of white supremacy” (Davis & Martin, 2008, p. 14).

Many students of color recognize the existence of scientific racism even if it is not overtly named by them. This tacit and/or cultural knowledge may manifest itself as resistance to science as is currently taught (Boutte, 2002; Kohl, 2007). Notwithstanding, science educators will need preparation for leading discussions on scientific racism and other sociopolitical realities. Admittedly, this dimension of culturally relevant teaching is typically not addressed because of educators’ discomfort and/or little preparation. CRP is openly political whereas conventional teaching is not. Helping educators see the political nature of conventional teaching which privileges Eurocentric culture and positivist epistemologies is a formidable task.

To illustrate the Eurocentric nature of science, consider the typical “linear” steps for the “scientific method” as a framework for investigating the natural world. “Within this tradition, Jean Lamark is credited with discovering a theory of evolution, Watson and Crick discovered the structure of the DNA molecule, and Boyle discovered gas laws” (Barba, 1995, p. 56).

The step-driven scientific method is presented as a single way of investigating the world rather than as open to multifaceted possibilities (Boutte, 1999). According to this line of reasoning, if a scientist or group of people does not follow the step formula, the results are typically not considered “scientific.” Yet, for thousands of years, Native Americans of the Southwestern United States, South America, and Central America have cultivated corn. Each year the biggest and best ears of corn were saved by the harvesters and used as seeds the following year. The tradition of sowing only genetically superior seeds resulted in the improvement of corn from stubby little weeds into the current version of well-formed ears of corn (Barba, 1995).

In this example, Native Americans followed a scientific process (identified the problem, collected information about which ears of corn were the best, formed the hypothesis that planting the biggest seeds would result in an improved plant, conducted experiments in plant growth for thousands of years, and passed on the findings orally to their children). However, Native Americans are not viewed as the founders of genetics research because they did not keep written records of their research or present findings for peer review in the
“scientific” community. Credit for the discovery of genetics research is given to Gregor Mendel in many science textbooks. Sociopolitically, culturally relevant teaching would question whether Mendel alone discovered genetics research and would explore evidence of others who had previously discovered this. A Eurocentric view of science which insists on keeping copious notes, writing reports and the like, dismisses and overlooks the research of generations of Native Americans (Barba, 1995). Here it becomes obvious that science is not “objective,” “neutral,” or “factual.” Like all disciplines, it represents the worldviews of the writers of the (science) texts. Why would a Native American or other student of color find this version of science credible, especially when Eurocentric worldviews dominate the texts and discounts other versions?

Current science content which is dominated by discoveries attributed to White males also omits contributions from women whose work was frequently claimed by White male colleagues or husbands (Barba, 1995; Ryan, 2008). There are numerous other examples beyond the scope of this article: Onesimus, an African American slave who shared information from Africa with his master about the smallpox vaccine; Maria Aimee Lullin’s discoveries regarding honeybees published under her husband’s name, Francois Huber; Rosalind Franklin’s contribution to the discovery of Deoxyribonucleic Acid (DNA) being credited to the works of only Watson and Crick; countless unrecorded instances which demonstrate how scientific contributions of women and people of color were deliberately omitted from “scientific” records and false information conveyed to generations of students. Dialogue on such topics reframes science from being static to dynamic and intimates that as more accurate and complete information is uncovered the knowledge base in science should reflect these changes (Kuhn, 1996). Additionally, students can start to look for examples of science in their everyday occurrences.

Traditionally, science content has focused on “received” knowledge which is dominated by Eurocentric thought. Hence, the focus has too often been on giving the right answer versus problem solving and problem posing (Freire, 1970/1999). Culturally relevant pedagogy acknowledges that the history of science and science teaching has been oversimplified. Hence, it seeks to explore science from various ages and civilizations throughout human history.

Given the backdrop of “traditional” approaches, culturally relevant science aims to include voices and worldviews that have been silenced and excluded from the curriculum (Barton, Ermer, Burkett, & Osborne, 2003; Keane, 2008; Mckinley, Brayboy, & Castagno, 2008; Ryan, 2008). This does not mean negating or excluding information from Eurocentric or Western worldviews, but it does mean substantively including other worldviews as opposed to occasional or fragmented instances. Without culturally relevant science approaches, not only will a variety of worldviews be omitted, but existing hegemonic power structures will be reinforced (Ryan, 2008). From a critically conscious perspective, students will move beyond false binaries, dualistic and/or essentialist views which suggest that there is one way of knowing science (Fleer, 2008). Hence, when they come to understand that science is also about people’s relationships to others and to
the phenomenal world, many perspectives (even contradictory or oppositional ones) can co-exist (Fleer, 2008; Keane, 2008). Conceptually, culturally relevant science defies the assertion that there is a singular or normative scientific worldview. It recognizes that there is a wide range of scientific skills and ways of knowing that people display in their lived experiences within diverse communities.

Pedagogically, Fleer (2008) recommends that teachers use a “double move” approach in which they have in mind the everyday practices, traditions, or concepts of their students as well as the Western scientific concept(s) that they want students to acquire. “Having both in mind (double move) allows teachers to be respectful and mindful of the practice traditions, whilst at the same time seeking pedagogical ways of giving more meaning to Western scientific concepts” (Fleer, 2008, p. 785).

It is particularly important for science educators to rethink their approaches for teaching science since many students consider it irrelevant to their lives (Barba, 1995; Boutte, 1999; Lee & Buxton, 2008). Additionally, females and students of color (with the exception of Asian Americans as a group) tend to do less well than White males in science (Boutte, 1999). While no cultural group is monolithic, the inclusion of culturally syntonic considerations for diverse learners is suggested. That is, attention should be given to see if the instruction, curriculum, and assessments are attuned to the students’ cultural worldviews. Culturally syntonic examples can include making sure that the imagery in textbooks and classrooms reflect the students, the use of culturally familiar role models, or classroom activities which build on the communication strengths of the students: e.g., oral tradition for African American students (Barba, 1995; Lee & Luykx, 2005).

Conclusion

It is commendable that educators like CKJ have the presence of mind and commitment to believe that high achievement is possible for African American students. The expectation that educators will be able to transform their classrooms overnight is unreasonable and unfeasible. It is important to recognize the hugeness and complexity of what educators on the frontline are up against: the status quo which has built-in reinforcements to protect itself. So we applaud CKJ’s efforts while acknowledging that she must delve deeper and be vigilant about addressing issues of equity, power, and culture. Currently, she is focusing narrowly on individual activities which primarily emanate from the textbook.

Since culturally relevant teaching is a bridge to mainstream and other ways of knowing, not all activities/lessons included in classes are expected to focus only on students’ respective cultural groups. Understanding students and developing strong relationships and respect is foundational to the process (Bonner, 2009). We have tried to capture a deep sense of centering culture, politics, and achievement in classrooms for culturally and linguistically diverse
students. One goal is to find ways to normalize high achievement for African American students so that they will realize and regain their historical legacies of achieving. To do so requires becoming familiar with the context, students, and their cultures. Often additional reading will be necessary, as well as deconstructing, reconstructing, and reframing science teaching to African American and other culturally and linguistically diverse students. Educators will need to engage in an ongoing process of countering pervasive and long-held disbeliefs that African American students are scientifically brilliant and capable. While our focus has been on African American students (whom we do not consider to be monolithic, by the way), the same process is required for other cultural groups. Educators will need to be well-versed in the academic literature and ethnographic information about the centrality of culture in teaching and learning. Attention will need to be given to the educational, social, and political implications of our role as educators in privileging the work and worldviews of White male scientists in classroom instruction and curriculum.

In the process, educators may need to reposition themselves as teachers and learners (Freire, 1970/1999) and view students as a source of information, letting them research topics. Community members and others are also sources of wisdom (Boutte & Hill, 2006). Collaboration with other science educators will likely make the process more interesting and insightful as well as less threatening. Like scientific inquiry, the process of culturally relevant teaching is a dynamic and ongoing process. Educators will need to remain open to refining and transforming their thinking. Culturally relevant teaching is a continuous quest, not a destination. It is hoped that teachers engage in culturally relevant pedagogy not solely to reduce the “achievement gap” or as a trend, but because it is an ethical and educational imperative that all students be effectively taught in light of pervasive and persistent educational trends.

Note

1. We will refer to the author by her initials (CKJ) throughout the article.

References


Rousseau, C., & Tate, W. F. (2003). No time like the present: Reflecting on equity in school mathematics. Theory into Practice, 42(3), 210-216.


### Appendix

Table 1. “Let The Cell Say Amen”: A student project for the Cell Analogies Collage assignment that used Christianity analogies

<table>
<thead>
<tr>
<th></th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Chloroplast=Pastor: the chloroplast converts energy of sunlight into chemical energy that the plant can use as the pastor converts the nutrients in the Bible into a Rama word for the followers</td>
</tr>
<tr>
<td>2</td>
<td>Chromatin=Bible: the chromatin holds the DNA (directions on how each cell should behave) as the Bible holds the directions on how each Christian should behave while on earth</td>
</tr>
<tr>
<td>3</td>
<td>Nucleus=God: the nucleus is the center of the cell that gives instructions to the whole cell as God is the center of the church as he instructs the pastor on what to say to his people</td>
</tr>
<tr>
<td>4</td>
<td>Cell Wall=Church: the cell wall keeps the plant cell intact structurally as the church is a building where the believers of Christ can come and structurally worship God.</td>
</tr>
<tr>
<td>5</td>
<td>Microvilli=Congregation: the microvilli add surface area to the cell as the congregation adds surface area to the church.</td>
</tr>
<tr>
<td>6</td>
<td>Golgi Apparatus=Ministers: the golgi apparatus is involved in the synthesis of proteins for the cell's use as ministers of the church are responsible for aiding the pastor in the synthesis of the word for the digestion/use of the congregation.</td>
</tr>
<tr>
<td>7</td>
<td>Plasmodesmata=Holy Spirit: the plasmodesmata connects the cytoplasm of different cells as the Holy Spirit connect different churches who believe in God, the father, son, and Holy Spirit</td>
</tr>
<tr>
<td>8</td>
<td>Ribosome=Jesus: the ribosome is the pathway where proteins are made as Jesus Christ is the pathway that Christians take to get to heaven</td>
</tr>
<tr>
<td>9</td>
<td>Nuclear Envelope=Heaven: the nuclear envelope houses the nucleus as heaven is God’s home</td>
</tr>
<tr>
<td>10</td>
<td>Peroxisome=Church Ministries: the peroxisome has specialized metabolic functions, as the ministries of the church are responsible for carrying out certain tasks that aid the congregation and the pastor in spiritual growth.</td>
</tr>
</tbody>
</table>
CULT OF PEDAGOGY
(http://www.cultofpedagogy.com/)

TEACHER NERDS, UNITE.

3 Tips to Make Any Lesson More Culturally Responsive

Posted on April 1, 2015 (http://www.cultofpedagogy.com/culturally-responsive-teaching-strategies/) by Zaretta Hammond (http://www.cultofpedagogy.com/author/zaretta-hammond/)

Last month, I reviewed Zaretta Hammond’s fantastic book, Culturally Responsive Teaching and the Brain (http://www.cultofpedagogy.com/closing-achievement-gap-hammond/). Now I’m proud to have Zaretta here as a guest writer to share some specific strategies with us.

**Culturally responsive teaching.** Everybody is talking about it. The big question is: How do you actually make lessons culturally responsive? That comes up regularly when I am working with groups of teachers to improve outcomes for diverse students who are struggling. I remember working with a group of sixth grade teachers on improving learning for their at-risk students. These teachers were frustrated that their students,
95 percent of them students of color and English language learners, were not applying themselves to learning.

I suggested that we explore making lessons more culturally relevant in order to accelerate student learning. I remember the reaction of Janice, the science teacher. “I am not going to be rappin’ about the periodic table,” she said defiantly as she crossed her arms and sat back in her chair.

I couldn’t blame her. Google “culturally responsive teaching” and you can find a dozen videos of well-meaning teachers leading some call-and-response chant about exponents or rapping about the Boston Tea Party while students sit back and giggle. That’s because we usually talk about culturally responsive teaching only as an engagement strategy designed to motivate at-risk students to take learning seriously. Or we try to find a race-based connection to the content to make it “relevant” to minority students.

What IS culturally responsive teaching?

One of the biggest misconceptions about culturally responsive teaching is thinking you have to tie the lesson’s content to African American or Latino students’ racial background. The common belief is if you mention Africa, Mexico, or famous black and brown high achievers, it will spark students’ attention. Then they will be motivated to participate.

In reality, culturally responsive teaching is less about using racial pride as a motivator and more about mimicking students’ cultural learning styles and tools. These are the strategies their moms, dads, grandmas, and other community folks use to teach them life skills and basic concepts long before they come to school and during out-of-school time.

Culturally responsive teaching leverages the brain’s memory systems and information processing structures. Why? Many diverse students come from oral cultural traditions. This means their primary ways of knowledge transfer and meaning-making are oral and active. It’s a common cultural tradition that cuts across racial groups: African American, Latino, Southeast Asian, and Pacific Islander communities all have strong oral cultures. Each of these cultural groups uses the brain’s memory systems for turning inert information into useable knowledge. They use memory strategies to make learning sticky, like connecting what needs to be remembered to a rhythm or music (that’s why we still know the ABC song) or by reciting it in fun ways like a poem, riddle, or limerick.

I asked Janice what area of learning she wanted to help her kids improve. She said science vocabulary; they weren’t learning the weekly words and it was getting in the way of their understanding of key concepts. She was frustrated and at the end of her rope. I asked how she was teaching it. She used the typical approach: On Monday, she
listed the words on the board. Students copied them down and were required to look each word up and use it in a sentence. On Wednesday, there was a vocabulary test.

I suggested that we design word study to be more culturally responsive by making it more like the students’ own cultural learning process. She was open for trying something different.

I offered her these three tips for transforming any lesson into something that looked and felt more culturally responsive to diverse students, something that would allow them to engage more and process the content effectively.

1. **Gamify it.**

Games are the power strategy for culturally-grounded learning because they get the brain’s attention and require active processing. Attention is the first step in learning. We cannot learn, remember, or understand what we don’t first pay attention to. Call and response is just a way to get the brain’s attention. Most games employ a lot of the cultural tools you’d find in oral traditions – repetition, solving a puzzle, making connections between things that don’t seem to be related (Ever play Taboo or Apples to Apples?).

2. **Make it social.**

Organizing learning so that students rely on each other will build on diverse students’ communal orientation. This communal orientation can be summed up in the African proverb, “I am because we are.” Even making learning slightly competitive in a good-natured way increases students’ level of attention and engagement. It’s why the T.V. show Survivor has been around for so many years; it’s a social-based game.

3. **Storify it.**
The brain is wired to remember stories and to use the story structure to make sense of the world. That's why every culture has creation stories. In oral traditions, stories play a bigger role in teaching lessons about manners, morality, or simply what plants to eat or not eat in the wilderness because it's the way content is remembered. Diverse students (and all students, really) learn content more effectively if they can create a coherent narrative about the topic or process presented. That's the brain's way of weaving it all together. (Bonus: It also offers a great way to check for understanding and correct misconceptions.)

So Janice took her weekly list of science vocabulary and created a variety of sorting and matching games for students. She built a set of simple card games based on Go Fish or Old Maid. In addition she created some team games. Each week students had different active ways to learn the vocabulary. For 10-15 minutes a couple of times during the week, students got to play these learning games rather than look up words in a dictionary. She gave them instructions for making the games at home if they wanted to.

Instead of the traditional weekly vocab test, she asked them to “storify” their understanding of key concept words like metamorphosis, using vocabulary from past weeks.

When I checked in with the group a few weeks later, she was the first one to share. She said student engagement was like night and day. Now all students were participating. She said she knew they were learning the vocabulary at a deeper level because they were actually using the new science terms during discussions and in their writing with no prompting from her.

The big A-ha’s for the group that day were that (1) Culturally responsive teaching doesn’t have to be some performance the teacher does to entertain students and (2) it doesn’t have to mention race or reference culture at all. Instead, what makes a practice culturally responsive is that it mimics students’ own cultural learning tools. They all realized that these practices are helpful for all students, not targeted at minority students.

The real trick is to use these strategies regularly as part of your instructional routine rather than doing them randomly every now and then. Consistency is the key.
3 Tips to Make Any Lesson More Culturally Responsive

Culturally responsive teaching is less about using racial pride as a motivator and more about mimicking students’ cultural learning styles and tools.

1. Gamify It.

Most games employ a lot of the cultural tools you’d find in oral traditions – repetition, solving a puzzle, making connections between things that don’t seem to be related.

2. Make It Social.

Organizing learning so that students rely on each other will build on diverse students’ communal orientation.

3. Storify It.

Diverse students (and all students, really) learn content more effectively if they can create a coherent narrative about the topic or process presented.

Learn more about how to improve diverse students’ information processing skills and actually grow their brains in Zaretta Hammond’s book, Culturally Responsive Teaching and The Brain: Promoting Authentic Engagement and Rigor Among Culturally and Linguistically Diverse Students.
The Science and Policy of Biodiversity
There is a place in the Sonoran Desert borderlands which, more than any other I know, capsulizes what the term diversity has come to mean to both natural and social scientists alike. The place is a desert oasis known as Quitobaquito, centered on a spring-fed wetland at the base of some cactus-stippled hills that lie smack dab on the U.S.-Mexico border. Whenever I walk around there, I am astounded by the curious juxtapositions of water-loving and drought-tolerating plants, of micro-moths wedded to single senita cacti, and hummingbirds that have traveled hundreds of miles to visit ocotillos, of prehistoric potsherds of ancient Patayan and Hohokam cultures side by side with broken glass fragments left by O'odham, Anglo-and Hispanic-American cultures.

Walk down from its ridges of granite, schist, and gneiss, and you will see organpipe cactus growing within a few yards of arrowweed, cattails, and bulrushes immersed in silty, saline sediments. The oasis has its own peculiar population of desert pupfish in artesian springs just a stone's throw from the spot where a native caper tree makes its only appearance in the United States. The tree itself is the only known food source for the pierid butterfly that is restricted in range to the Sonoran Desert proper.

More than 270 plant species, over a hundred bird species, and innumerable insects find Quitobaquito to be a moist harbor on the edge of a sea of sand and cinder. Not far to the west of this oasis, there are volcanic ridges that have frequently suffered consecutive years without measurable rainfall, and their impoverished plant and animal communities reflect that.

Quitobaquito is naturally diverse, but its diversity has also been enhanced rather than permanently harmed by centuries of human occupation. Prehistoric Hohokam and Patayan, historic Tohono O'odham, Hia c-ed O'odham, Apache, Cucupa, and Pai Pai visited Quitobaquito for food and drink long before European missionaries first arrived there in 1698. Since that time, a stream of residents from O'odham, Mexican, Jewish, and Mormon families have excavated ponds and irrigation ditches, transplanting shade and fruit trees alongside them. They intentionally introduced useful plants, and accidentally brought along weedy camp-followers, adding some fifty plant species to Quitobaquito over the centuries. Native birds and mammals have also been affected by human presence there, and some increased in number during the days of O'odham farming downstream from the springs. All in all, Quitobaquito's history demonstrates that the desert's cultural diversity has not necessarily been antithetical to its biological diversity; the two are historically intertwined.

In fact, the Sonoran Desert is a showcase for understanding the curious interactions between cultural and biological diversity. There are at least seventeen extant indigenous cultures that each has its own brand of land management traditions, as well as the dominant Anglo- and Hispanic-American cultures which have brought other land ethics, technologies, and strategies for managing desert lands into the region. While some cultural communities such as the Seri were formerly considered passive recipients of whatever biodiversity occurred in their homeland, we now know that they actively dispersed and managed populations of chuckwallas, spiny-tailed iguanas, and columnar cacti. Floodwater farmers such as the Tohono O'odham and Opata dammed and diverted intermittent watercourses, planted Mesoamerican crops, and developed their own domesticated crops from devil's claw, tepary beans, and Sonoran panic grass. Anglo-and Hispanic-American farmers and ranchers initiated other plant and animal introductions, and
dammed rivers on a much larger scale. Each of these cultures has interacted with native and exotic species at different levels of intensity, including them in their economies, stories, and songs. From an O'odham rainmaking song that echoes the sound of spadefoots, to the Western ballad "Tumblin' Tumbleweeds" written in Tucson over a half century ago, native and invasive species have populated our oral and written traditions as curses, cures, and resources.

Technically speaking, this stuff we call diversity eludes one single definition. For starters, however, biodiversity (short for biological diversity) can be generally thought of as the "variety of life on earth." Scientists use this term when discussing the richness of life forms and the heterogeneity of habitats found within or among particular regions. Biodiversity in this sense is often indicated by the relative richness of species in one habitat versus another. Thus it is fair to say that riparian gallery forests of cottonwoods and willows along desert rivers typically support more avian biodiversity—a greater number of bird species—than do adjacent uplands covered with desertscrub vegetation. Similarly, there is greater biodiversity in flowering vines in the moist tropical forests of southern Mexico than there is in the Sonoran Desert of northern Mexico.

It is worth noting, however, that ecologists such as E.O. Wilson first coined the term biodiversity to signify something far more complex than the mere number of species (termed species richness) found in any given area. Usually ecologists also consider the number of individuals within each species when they assess diversity or heterogeneity. An area where one desert wildflower such as the California poppy dominates eight other species is considered to be less diverse than an area with the same eight species where the numbers of each are more evenly distributed. As Kent Redford of The Nature Conservancy has recently explained, "A species-focused approach to biodiversity has proved limiting for a number of reasons....[The] use of just species as a measure of biodiversity has resulted in conservation efforts focusing on relatively few ecosystems while other threatened ones are highly ignored. Species do not exist in a vacuum, and any definition of biodiversity must include the ecological complexes in which organisms naturally occur and the ways they interact with each other and with their surroundings."

The integrity of biodiversity can be teased apart into the following components. Although each of them may be separated out by scientists for study, they do not truly exist "apart" from one another.

**ECOSYSTEM DIVERSITY**

The variety of landscapes found together within any region, and the ways in which their biotic communities interact with a shared physical environment, such as a watershed or coastal plain. A landscape interspersed with native desert vegetation, oasis-like cienegas, riparian woodlands, and croplands is more diverse than one covered entirely by one crop such as cotton. The Colorado River Delta was once a stellar example of ecosystem diversity, displaying a breath-taking mixture of riparian gallery forests, closed-canopy mesquite bosques, saltgrass flats, backwater sloughs, rivers, ponds, and Indian fields. Much of it is now dead, except for the hypersaline wetlands known as the Cienega de Santa Clara.

**BIOTIC COMMUNITY DIVERSITY**

The richness of plants, animals, and microbes found together within any single landscape mosaic; such a mosaic can range in scope from the regional to the watershed level. This richness can be shaped by a variety of factors, ranging from the age of the vegetation to land use to soil salinity and fertility. For example, the number of species on well-drained, ungrazed desert mountain slopes covered by columnar cacti, ancient desert ironwoods, and spring wildflowers is greater than that on an alkali flat grazed by goats, where only saltbush, saltgrass, and seepweed may grow. The Rincon mountains east of Tucson demonstrate a gradient of communities, each with its own diversity, as they rise from desertscrub to xeric woodlands, and coniferous forests.
INTERACTION DIVERSITY
The complexity of interactions within any particular habitat, such as the relationships between plant and pollinator, seeds and their dispersers, and symbiotic bacteria and their legumes. A pine-oak woodland in Arizona's "sky islands" harbors more interspecific interactions than does an even-aged pine plantation. Ramsey Canyon in the Huachua mountains showcases such interaction diversity, with over a dozen hummingbirds, as well as bats, bees, and butterflies visiting its myriad summer flowers.

SPECIES DIVERSITY
The richness of living species found at local, ecosystem, or regional scales. A well-managed desert grassland hosts more species than can be found in a buffelgrass pasture intentionally planted to provide livestock forage without consideration of wildlife needs. Quitobaquito, discussed above, is as fine an example of localized species diversity as we have anywhere in the binational Southwest.

GENETIC DIVERSITY
The heritable variation within and between closely-related species. A canyon with six species of wild out-crossing beans contains more genetic variation than does a field of a single highly-bred hybrid bean. Indian fields in southern Sonora demonstrate this concept, for their squashes hybridize with weedy fieldside gourds, and their cultivated chile peppers are inflamed by genetic exchange with wild chiltepines.

All of these components of biodiversity ensure some form of environmental stability to the inhabitants of a particular place. A landscape with high ecosystem diversity is not as vulnerable to property-damaging floods as a bladed landscape is, for a mix of desert grassland and wetlands serves to buffer downstream inhabitants from rapid inundations. A diverse biotic community is less likely to be ravaged by chestnut blight or spruce budworm than a tree plantation can be. A cactus forest with diverse species of native, wild bees is less vulnerable to fruit crop failure than are orchards or croplands that are exclusively dependent upon the non-native honeybees. A desert grassland with multiple species of grasses and legumes cannot be as easily depleted of its fertility and then eroded as can one with a single kind of pasture grass sucking all available nutrients out of the ground. And finally, a Pima Indian garden intercropped with many different kinds of vegetable varieties will not succumb to white flies or other pests as easily as will an expansive, irrigated lettuce field in the Imperial Valley.

In short, more of "nature's services" - the economic contributions offered by intact ecosystems-are possible when we manage these ecosystems to safeguard or restore their biodiversity, and not allow it to be depleted. Recent estimates by environmental economists suggest that the dollar value of the services such as flood protection and air purification provided by the world's intact wild ecosystems averages thirty-three trillion dollars per year, compared to the eighteen trillion dollar Gross National Product of all nations' human-made products.

The message is clear: when a mosaic of biotic communities is saved together and kept healthy within a larger landscape, few endangered species fall between the cracks and succumb to extinction processes. In contrast, a small wildlife sanctuary designed to save a single species often fails to achieve its goal, for the other organisms which that species ultimately needs in its presence have been ignored or eliminated. Not only do humans benefit from the conservation of large wildlands landscapes, but many other species do as well.

How does this play out in our Sonoran Desert region?

Ask most people to characterize life in the desert and few will think to mention the word "diversity"as part of their thumbnail sketch of this place. Most of us keep in our heads those pictures of bleak, barren, blowing sandscapes when we hear the word "desert."
The Sonoran Desert does contain one major sea of sand, as well as a long corridor of coastal dunes along the Gulf of California, but even these are seasonally lush with unique and thriving life forms. As one spends more time in a range of Sonoran Desert habitats, one is constantly surprised by how many plants and animals are harbored here.

Travel out of Sonoran Desert vegetation into the higher mountain ranges held within the region and even more astonishing levels of biodiversity can be found. In fact, the "sky islands" of southeastern Arizona and adjacent Sonora are now recognized by the Inter-national Union for the Conservation of Nature as one of the great centers of plant diversity north of the tropics.

When we compare our desert with others, the contrast is striking. Overall, the Sonoran Desert has the greatest diversity of plant growth forms- architectural strategies for dealing with heat and drought-of any desert in the world. From giant cacti to sand-loving underground root parasites, some seventeen different growth forms coexist within the region. Often, as many as ten complementary architectural strategies will be found together, allowing many life forms to coexist in the same patch of desert.

Biodiversity in the desert is often measured on a scale that would not be used in the tropical rainforest. Desert ecologists have found twenty kinds of wildflowers growing together in a single square yard (.84 sq. m), while a single tropical tree might take up the same amount of space. On an acre (.4 ha) of cactus forest in the Tucson Basin, seventy-five to 100 species of native plants share the space that three mangrove shrubs might cover in swamp along a tropical coast. These levels of diversity are a far cry from the "bleak and barren" stereotype, and it may well be that the Sonoran Desert region is more diverse than other arid zones of comparable size.

Consider for example, the flora of the Tucson Mountains, which Arizona-Sonora Desert Museum research scientists recently inventoried with a number of their colleagues. In an area of less than forty square miles (100 sq. km), this botany team encountered over 630 plant species-as rich a local assortment of plants as any desert flora we know. This small area contains roughly one-sixth of the Sonoran Desert's entire plant diversity. It is disproportionately rich relative to its size, its paucity of surface water, and its elevational range.

Such a diversity of wildflowers and blossoming trees attracts a diversity of wildlife as well. In the Sonoran Desert area within a thirty mile radius of Tucson, you can find between 1000 and 1200 twig- and ground-nesting native bees (all of them virtually "stingless"). As the Desert Museum's research associate Stephen Buchmann wryly notes, "this may mean that the Sonoran Desert region is the richest bee real estate anywhere in the world-the entire North American continent has only 5000 native bee species."

Desert wildflowers attract more than bees. Southern Arizona receives visits from more hummingbird species-seventeen in all-than anywhere else in the U.S. Other pollinator groups, such as butterflies and moths, are well-represented in the region as well. Single canyons near the Arizona-Sonora border may harbor as many as 100 to 120 butterfly species, and moth species may number five to ten times higher than that in the same habitats. When all pollinating organisms breeding or passing through here are counted, it may be that the greater Sonoran Desert has as large a pollinator fauna as any bioregion in the world.

This region is also rich in small mammals and reptiles. Some eighty-six species of mammals have ranges centered within the San Pedro National Riparian Area alone, a record unsurpassed by any natural landscape of comparable size in the U.S.; the area contains half of all mammal species in the binational Sonoran Desert. At least ninety-six species of reptiles are endemic to the Sonoran Desert-found here and nowhere else in the world.
Why is such diversity present in a land of little rain? For starters, our bimodal rainfall pattern brings out completely different suites of wild-flowers and their attendant insects at different times of the year. In addition, we benefit from a more gradual transition between tropical nature and desert nature than does the Chihuahuan Desert on the other side of the Sierra Madre—many tropically-derived life forms reach their northernmost limits in the Sonoran Desert due to its relatively frost-free climes. Of course, tropic rainforests are much more diverse in the total number of species they have throughout their biome, in part because of their ages and their high energy budgets. However, there may be more turnover in species from place to place in the Sonoran Desert than in some tropical vegetation types. That is to say, many desert plants and insects are "micro-areal"—occurring only within a 100 by 100 mile spots on the map. Particularly in Baja California, there are extremely high levels of endemism, including some 552 plants unique to the peninsula.

Nevertheless, it remains true that the highest levels of local diversity in this desert region occur where water accumulates. Some of the highest breeding bird densities recorded anywhere in the world come from riparian forests along the Verde and San Pedro river floodplains. More than 450 kinds of birds have historically nested or migrated along the Colorado, San Pedro, and Santa Cruz rivers. And yet, if riparian habitats were among our richest, what have we lost with the removal of cottonwoods from ninety percent of their former habitat in Arizona? Ornithologists cannot name a single Sonoran Desert bird that has gone extinct with riparian habitat loss, but many of the eighty species of birds dependent on these riparian forests have locally declined in abundance. A single desert riparian mammal—Merriam's mesquite mouse—is now extinct due to the loss of riparian habitat at the hand of groundwater pumping, arroyo cutting, and overgrazing. Mexican wolves and black bears that formerly frequented our river valleys are among those mammals no longer found in the Sonoran Desert proper.

Conservation International has estimated that as much as sixty percent of the entire Sonoran Desert surface is no longer covered with native vegetation but is dominated by the 380-some alien species introduced to the region by humans and their livestock. Alien plants such as buffelgrass now cover more than 1,400,000 acres of the region, at the expense of both native plants and animals. Tamarisk trees choke out native willow and cottonwood seedlings. Invasive weeds such as Johnson grass and Sahara mustard have taken over much of certain wildlife sanctuaries and parks in the desert, outcompeting rare native species. Other invasive species such as Africanized bees and cowbirds also compete with the native fauna. Biological invasions are now rated among the top ten threats to the integrity of Sonoran Desert ecosystems, whereas a half century ago they hardly concerned ecologists working in the region. These invaders somehow reach even the most remote stretches of the desert, to the point of being ubiquitous.

The wholesale replacement of natives by aliens is enough of a problem, but desert biodiversity has been even more profoundly affected by habitat fragmentation—the fracturing of large tracts of desert into pieces so small that they cannot sustain the interactions among plant, pollinator, and seed disperser. Such fragmentation does not necessarily lead to immediate extinctions, just declines—there is a time lag before a species' loss of interactions with others leads to complete reproductive failure. Fragmentation caused by urbanization is now considered the number-one threat to the biodiversity of the region and is not expected to diminish during our lifetimes. The population of Arizona's Maricopa County in the year 2025 is expected to be two and a half times what it was in 1995, and similar growth rates are anticipated along the entire desert coastline of the Sea of Cortez.

In a sense, humans are making the Sonoran Desert much more like the old (and erroneous) stereotype of a barren wasteland. As more than forty dams were constructed along rivers in this century, old-timers witnessed hundreds of miles of riparian corridors dry up. Groundwater overdraft has also impoverished desert and riparian vegetation, as farms and cities pump millions more acre-feet out of the ground than rainfall in the region can naturally recharge. The roots of plants are left high and dry above the water table.
Most of the Sonoran Desert was not at all naturally barren, but our misunderstandings have impoverished one of the richest arid landscapes on the planet. That is why the Desert Museum has endorsed a long-term Conservation Mission Statement which begins with these words from ecologist D.M. Bowman:

"So what is biodiversity?...the variety of life on this planet is like an extra-ordinarily complex, unfinished, and incomplete manuscript with a hugely varied alphabet, an ever-expanding lexicon, and a poorly understood grammar....Ripping the manuscript to pieces because we want to use the paper makes little sense, especially if the manuscript says that 'to survive you shall not destroy what you do not understand'. Our mission as ecologists must be to interpret the meaning of biodiversity. The urgent need for this mission, and our current ecological ignorance, must be forcefully communicated to the public."

Instead of seeing future inhabitants rip out any more pages essential to the desert's story, the conservation organizations of the region have begun to work together to ensure that the most important corridors and secluded refugia for desert flora and fauna are identified and protected or restored. These critical areas - essential to the flow of diversity from source to sink, from headwaters to river mouth, and from tropical wintergrounds to summer nesting areas - must be kept from further fraying if the fabric of the Sonoran Desert is to remain intact. Scientists can prioritize such areas in terms of their value to biodiversity, but they will be safeguarded for future generations only if a broad spectrum of society is involved in endorsing their protection.

References


Life has existed on Earth for over 3.5 billion years. Over 95% of the species that ever existed have gone extinct. So why should we be concerned about current extinction rates and conserving biodiversity?

Currently the planet is inhabited by several million species in about 100 different phyla (Dirzo & Raven 2003). About 1.8 million have been described by scientists (Hilton-Taylor et al. 2008), but conservative estimates suggest that there are 5–15 million species alive today (May, 2000), since many groups of organisms remain poorly studied. Over 15,000 new species are described each year (Dirzo & Raven 2003), and new species are evolving during our lifetimes. However, modern extinction rates are high, at 100 to 1000 times greater than background extinction rates calculated over the eras (Hambler 2004). Although new species appear, existing species go extinct at a rate 1000 times that of species formation (Wilson 2003). Many biologists agree that we are in the midst of a mass extinction, a time when 75% or more of species are lost over a short geological time scale (Raup 1994). The last great mass extinction was 65 million years ago, at the end of the Cretaceous, when the dinosaurs went extinct. The International Union for the Conservation of Nature estimates that 22% of known mammals, 32% of amphibians, 14% of birds, and 32% of gymnosperms (all well-studied groups) are threatened with extinction (Hilton-Taylor et al. 2008). Species that were abundant within the last 200 years have gone extinct. For example, passenger pigeons, which numbered three to five billion in the mid 1800s (Ellsworth & McComb 2003), are now extinct.

Why should we be concerned about this loss of biodiversity? The answer lies in the fact that, for the first time in Earth’s history, a single species, Homo sapiens, could cause a mass extinction, precipitating its...
own demise. The primary cause of today’s loss of biodiversity is habitat alteration caused by human activities.

Let’s think about the meaning of biodiversity. Most people understand that biodiversity includes the great heterogeneous assemblage of living organisms. This aspect of biodiversity is also known as "species diversity." Biodiversity includes two other components as well- genetic diversity and ecosystem diversity.

**Species diversity**

The 1.8 million species described by science are incredibly diverse. They range from tiny, single-celled microbes like *Nanoarchaeum equitans*, 400 nm in diameter living as parasites on other microbes in thermal vents at temperatures of 70–98°C (Huber et al. 2002), to giant organisms like *Sequoias*, blue whales, the "humungous fungus," and "Pando" (Figure 1). "Pando" is the name given to a clonal stand of aspen trees, all genetically identical and attached to each other by the roots (Grant et al. 1992). The stand covers 106 acres and weighs 13 million pounds. The "humungous fungus," a giant individual of the species *Armillaria osterae* is found in the state of Oregon, and covers 1,500 acres (USDA Forest Service 2003).

While people are generally most familiar with multicellular organisms such as plants and animals, these organisms form only small branches on the tree of life. The greatest metabolic diversity is found among the prokaryotic organisms of the Eubacteria and Archaea. Although some of these microbes use oxygen for respiration, or photosynthesize like plants, others have the extraordinary ability to derive energy from inorganic chemicals such as hydrogen sulfide or ammonia, and they use carbon dioxide as their only source of carbon for producing organic molecules. Organisms that we consider extremophiles can survive in saturated salt concentrations (36% compared to approximately 3% for seawater), or in superheated water in deep-sea vents and geysers. Because people have ventured to all parts of the globe, one might expect that the new species being discovered each year would be microscopic organisms that can only be distinguished at the metabolic level. While it is true that most new species identified are insects, microbes and fungi, we are still discovering new vertebrates (Figure 2), even sizable new vertebrates such as a new species of baleen whale and a clouded leopard. Since 2000, 53 new species of primates have been described (IUCN 2008) including a new species of Brazilian monkey, Mura’s saddleback tamarin.

**Genetic Diversity**

Genes are responsible for the traits exhibited by organisms and, as populations of species decrease in size or go extinct, unique genetic variants are lost. Since genes reside within species, why should we consider genetic diversity as a separate category? Because they hold "genetic potential." For example, many of the crops that we grow for food are grown in monocultures of genetically homogeneous individuals. Because all individuals are the same, a disease, insect pest, or environmental change that can kill one individual can extirpate an entire crop. Most of our high-yield varieties show significant reductions in yield within about 5 years, as pests overcome the crops’ natural defenses. Plant breeders look to wild plant relatives and to locally grown landraces to find new genetic varieties. They can then introduce these genes into crops to renew their vigor. However, according to the UN Food and Agriculture Organization, 96% of the 7,098 US
apple varieties cultivated prior to 1904, 95% of the US cabbage varieties, and 81% of tomato varieties, are extinct, and the genes that made these varieties unique are gone. Genetic variation allows species to evolve in response to diseases, predators, parasites, pollution, and climate change. The Red Queen Hypothesis, named for Lewis Carroll’s character who runs continually in order to stay in the same place, states that organisms must continually evolve, or succumb to their predators and parasites that will continue to evolve.

In addition to traditional breeding, advances in genetic engineering have allowed scientists to introduce beneficial genes from one species to another. For example, diabetics used to depend on insulin from human cadavers, or from cows or pigs. Human insulin was expensive, and non-human insulin could cause allergic reactions. Now we can isolate the gene that codes for human insulin, insert it into bacterial cells, and let the bacteria produce large quantities of human insulin. Other notable feats in genetic engineering include the introduction of genes that enhance the nutritive value of food, create crop resistance to insect pests, induce sheep to produce a protein for treating cystic fibrosis disease, and alter bacteria so that they can clean up toxic mine wastes through their metabolic activities. Many other genetic manipulations are currently in development.

**Ecosystem Diversity**

Ecosystems include all the species, plus all the abiotic factors characteristic of a region. For example, a desert ecosystem has soil, temperature, rainfall patterns, and solar radiation that affect not only what species occur there, but the morphology, behavior, and the interactions among those species (Figure 3). When ecosystems are intact, biological processes are preserved. These processes include nutrient and water cycling, harvesting light through photosynthesis, energy flow through the food web, and patterns of plant succession over time. A conservation focus on preserving ecosystems not only saves large numbers of species (including non-charismatic species that do not receive public support) but also preserves the support systems that maintain life.

**Figure 3: Physical features of an ecosystem affect what species survive there.**

(A) In sharp contrast to desert habitats, this lush spruce-fir forest near Berthoud Pass, in Colorado, receives an average of 38 inches of precipitation per year, largely in the form of snow. (B) The sandstone pinnacles of Goblin Valley, Utah occur in high desert in the San Rafael Swell. The area receives less than 8 inches of annual precipitation. (Courtesy of Jeffry Mitton)

**Why Conserve Biodiversity?**

From a selfish point of view, humans should be concerned about saving biodiversity because of the benefits it provides us–biological resources and ecosystem services. However, nature provides social and spiritual benefits as well.

**Biological Resources**

Biological resources are those products that we harvest from nature. These resources fall into several categories: food, medicine, fibers, wood products, and more. For example, over 7,000 species of plants are
used for food, although we rely heavily on only 12 major food crops. Most of the human population depends on plants for medicines. In the developed world, many of our medicines are chemicals produced by pharmaceutical companies, but the original formulas were often derived from plants. For example, opiate pain relievers are derived from poppies, aspirin is derived from willows, quinine for treating malaria comes from the Chinchona tree. The rosy periwinkle (Vinca rosea) and Pacific yew (Taxa brevifolia) both provide substances used in chemotherapy to inhibit the cell division of cancerous cells.

Fibers for clothing, ropes, sacking, webbing, netting, and other materials are provided by a large number of plants, including cotton plants, flax plants (linen), hemp (cordage and sail canvas), Agave plants (sisal), Corchorus plants (jute), bamboo and palms. Trees provide the wood products used in making homes, furniture, and paper products. In addition, living organisms provide inspiration for engineers seeking better and more efficient products. The field known as biomimicry is the study of natural products that provide solutions to human needs. For example, shark skin provided the model for hydrodynamic swimming suits. The glue used by Sandcastle worms (Phragmatopoma californica) to cement together their sand particle shells was the inspiration for a glue that mends fractured bones in the aqueous internal environment of the body. Finally, scientists are using the chemical nature of spider’s silk to design strong, lightweight fibers (Figure 4).

Ecosystem Services

Ecosystem services are processes provided by nature that support human life. These services include the decomposition of waste, pollination, water purification, moderation of floods, and renewal of soil fertility. Ecosystem processes are often overlooked, and are not generally valued as part of the economy until they cease to function. When economic value is assigned to these services, it is often startlingly high. For example, insect pollinators help produce many commercially important fruits such as almonds, melons, blueberries, and apples. The global economic value of pollination services performed by insects has been valued at $217 billion per year (Gallai et al. 2009).

How does a process like water purification work? Rain water is filtered by soil and by microbes that can break down nutrients and contaminants, and reduce metal ions, slowing their spread into the environment. Wetland and riparian plants absorb nitrogen, and trap sediments that decrease water quality.

Human construction and development disrupt natural environments, but most habitats have an extraordinary ability to recover when given the chance. This is because dormant seeds in the soil can germinate, stabilize the soil, and initiate successional events that restore vegetation which provides food and structure for other colonizing organisms. Native plants like fireweed can help revegetate an area after fire.

Social and Spiritual Benefits

Throughout most of human history, conservation has involved protecting nature for the spiritual gifts it provides, and protecting sacred places in the local landscape. Stories of indigenous people incorporate
detailed knowledge of the animals and plants that make up their world. The heterogeneity of the world’s mythology, folk art, and folk dances show the effects of biodiversity on cultural development, and contribute to the richness of global arts and literature (Figure 5).

Different cultures developed in different landscapes that influenced activities, occupations, diet, language, and architecture. Cultures adapted to local environmental challenges by growing local domestic crops, developing irrigation and terracing systems, hunting, fishing, and gathering. Biodiversity provides a sense of place. Countries and states have flagship animals and plants that are a source of pride and highlight the uniqueness of each habitat (Figure 6). Travel, which provides great pleasure to many people, is motivated by the desire to see this combination of cultural, landscape and biological diversity.

Ecotourism is travel with the desire to view, sustain, and support natural ecosystems and local cultures. Support from ecotourism can reduce habitat destruction, preserve species that suffer from poaching and illegal trade in the pet market, plus provide jobs for the local economy. For example, the Wasini Island Project in Kenya has been a major ecotourism success story. Coral reefs and mangrove forests were suffering degradation from development, agriculture, and from exploitation of reef species. Support from the Biodiversity Conservation Programme made it possible for the local community to build boardwalks and other features that facilitate viewing wildlife. Local people were trained as guides and in administration, and they now run a profitable ecotourism operation. Money from tourism helps the local economy, provides incentive to maintain the habitat, provides funds for the local health clinic, and scholarships for local students (Peopleandplanet.net 2009).
In recognition of the aesthetic value of nature, in 1892 the US Congress set aside the first national park "for the benefit and enjoyment of the people" (NPS 2010). Frederick Law Olmstead, who in the 1800s designed and managed park systems and urban parks such as Central Park in New York City, believed in the rejuvenating powers of nature. He felt that contemplating nature’s grandeur allowed man to put his life into perspective. In modern times, with increasing urbanization, people seek out local parks, open space and trails, and travel to national parks and wild places where they can enjoy nature. Birding, hiking, fishing, hunting, gardening, and other forms of recreation in nature are popular activities, and are economically important.

While modern arguments often focus on the anthropocentric value of biodiversity, nature writers such as Emerson, Thoreau, Leopold, Muir and many others emphasized the intrinsic values of biodiversity. As Henry David Thoreau said, "This curious world which we inhabit is more wonderful than it is convenient; more beautiful than it is useful; it is more to be admired and enjoyed than it is to be used" (1837).

References and Recommended Reading


IUCN. Extinction threat growing for mankind's closest relatives (2008).


Peopleandplanet.net. People and ecotourism. (2009)


Rising to the biodiversity challenge
ACKNOWLEDGEMENTS

Living Planet Index

The authors are extremely grateful to the following individuals and organizations for sharing their data: Richard Gregory and the European Bird Census Council for data from the Pan-European Common Bird Monitoring scheme; the Global Population Dynamics Database from the Centre for Population Biology, Imperial College London; Derek Pomeroy, Betty Lutaaya and Herbert Tushabe for data from the National Biodiversity Database, Makerere University Institute of Environment and Natural Resources, Uganda; Kristin Thorsrud Teien and Jorgen Randers, WWF-Norway; Pere Tomas-Vives, Christian Perennou, Driss Ezzine de Blas and Patrick Grillas, Tour du Valat, Camargue, France; Parks Canada; David Henry, Kluane Ecological Monitoring Project; Lisa Wilkinson, Alberta Fish and Wildlife Division. Many thanks to Chris Hails and Gordon Shepherd, WWF International, for their help and support on this project.

Ecological Footprint

Much of the background research for this report would not have been possible without the generous support of The Skoll Foundation, The Roy A. Hunt Foundation, Flora Family Foundation, Mental Insight Foundation, The Dudley Foundation, Erlenmeyer Stiftung and a dedicated community of individual donors.

PHOTOS

Front cover (left to right): WWF-Canon/Michel Terrettaz; WWF-Canon/Homo ambiens/R. Isotti-A. Cambone; WWF-Canon/Sébastien Rich; WWF/Catherine Holloway; WWF-Canon/Roger Le Guen. Page 7 (left to right, top to bottom): WWF-Canon/Jason Rubens; WWF-Canon/René Kaler; WWF-Canon/Michel Gunther; WWF-Canon/Homo ambiens/R. Isotti-A. Cambone; WWF-Canon/Roger Le Guen; WWF-Canon/Jo Benn; WWF-Canon/Roger Le Guen; WWF-Canon/Michel Gunther; WWF-Canon/Vladimir Filonov; WWF-Canon/Michel Terrettaz; WWF-CNRI/James W. Latourette.

Published in April 2008 by WWF–World Wide Fund For Nature (formerly World Wildlife Fund), Gland, Switzerland. Any reproduction in full or in part of this publication must mention the title and credit the above-mentioned publisher as the copyright owner.

© text and graphics: 2008 WWF All rights reserved

ISBN: 978-2-88085-287-0

The material and the geographical designations in this report do not imply the expression of any opinion whatsoever on the part of WWF concerning the legal status of any country, territory, or area, or concerning the delimitation of its frontiers or boundaries.

A BANSON Production Cambridge, UK

Published in Switzerland by Ropress on Acordia Verd Silk FSC, 40% recycled fibre and 60% virgin wood fibre, at least 50% of which is certified in accordance with the rules of FSC, using vegetable-oil-based inks.

WWF (also known as World Wildlife Fund in the USA and Canada) is one of the world’s largest and most experienced independent conservation organizations, with almost 5 million supporters and a global network active in over 100 countries. WWF’s mission is to stop the degradation of the planet’s natural environment and to build a future in which humans live in harmony with nature.

ZOOLOGICAL SOCIETY OF LONDON

Founded in 1826, the Zoological Society of London (ZSL) is an international scientific, conservation and educational charity: its key role is the conservation of animals and their habitats. ZSL runs ZSL London Zoo and ZSL Whipsnade Zoo, carries out scientific research in the Institute of Zoology and is actively involved in field conservation in over 30 countries worldwide. www.zsl.org

GLOBAL FOOTPRINT NETWORK

promotes a sustainable economy by advancing the Ecological Footprint, a tool that makes sustainability measurable. Together with its partners, the network coordinates research, develops methodological standards, and provides decision makers with robust resource accounts to help the human economy operate within the Earth’s ecological limits.
INTRODUCTION

At the start of the millennium the United Nations set a clear, measurable objective for biodiversity conservation. We are now only two years away from reporting on the target agreed by the Parties to the Convention on Biological Diversity (CBD) in 2002: to achieve by 2010 a significant reduction of the current rate of biodiversity loss at global, regional and national levels as a contribution to poverty alleviation and to the benefit of all life on Earth. The EU countries also agreed in 2002 to a more ambitious target – to halt biodiversity loss by 2010.

These targets mean that the public can hold the world’s governments collectively responsible for ensuring that global biodiversity is conserved, or at least that the rate of its loss is reduced. Regrettably, in 2008, it does not look as if sufficient effort has been made to stem the loss of biodiversity, and it appears unlikely that the global 2010 target will be achieved.

WWF uses two indicators to measure trends in the state of global biodiversity and the human demands on the biosphere. These indicators have also been adopted by the CBD, among a suite of indicators to assess progress towards the global 2010 target.

The first of the two, the Living Planet Index (LPI), developed in partnership with the Zoological Society of London, uses population trends in species from around the world to assess the state of global biodiversity. Over the past two years the coverage of the dataset has been expanded, methodological improvements made and better standards for LPI data implemented. The index tracks nearly 4,000 populations of 241 fish, 83 amphibian, 40 reptile, 811 bird and 302 mammal species. Indices for marine, terrestrial and freshwater species are calculated separately and then averaged to create an aggregated index. Between 1970 and 2005 the LPI declined by 27 per cent overall. Although the decline appears to have flattened out in the last few years, an analysis of switch points shows no significant change in the direction of the index since 1976, meaning that the 2010 target is very unlikely to be met.

The second is the Ecological Footprint, which measures human demands on the biosphere to produce resources and absorb carbon dioxide. Over the past three years, Global Footprint Network and its partner organizations have developed new methods and standards for calculating the Ecological Footprint (www.footprintstandards.org). They have also been working with countries to refine the data and methods used to evaluate national footprints. These collaborations have improved the analysis presented in this report. In 2003, the most recent year for which there are data, humanity’s total footprint exceeded the productive capacity of the biosphere by 25 per cent, and its rate of growth showed no sign of diminishing. This means that the fundamental drivers of biodiversity loss – the appropriation of the biosphere for the production of natural resources, and the disposal of associated waste products – are still increasing.

Figure 1: Global Living Planet Index. The average of three indices which measure overall trends in populations of terrestrial, marine and freshwater vertebrate species. The index declined by 27 per cent from 1970 to 2005.

Figure 2: Global Ecological Footprint. A measure of the productive capacity of the biosphere used to provide natural resources and absorb wastes. Humanity’s footprint was equivalent to about half of the Earth’s biologically productive capacity in 1961, but grew to a level 25 per cent above it in 2003.
**BIODIVERSITY LOSS AND THE HUMAN FOOTPRINT**

The Living Planet Index shows that wild species and natural ecosystems are under pressure to a greater or lesser degree across all biomes and regions of the world. The direct, anthropogenic threats to biodiversity are often grouped under five headings:

- habitat loss, fragmentation or change, especially due to agriculture
- overexploitation of species, especially due to fishing
- pollution
- the spread of invasive species or genes
- climate change.

All five of these threats stem ultimately from human demands on the biosphere – the production and consumption of natural resources for food and drink, energy or materials, and the disposal of associated waste products – or the displacement of natural ecosystems by towns, cities and infrastructure. Further, the massive flows of goods and people around the world have become a vector for the spread of alien species and diseases (see Figure 3).

Natural habitat, especially in terrestrial ecosystems, is lost, altered or fragmented through its conversion for cultivation, grazing, aquaculture, industrial or urban use. River systems are dammed and altered for irrigation, hydropower or flow regulation, and even marine ecosystems, particularly the seabed, are physically degraded by trawling, construction and extractive industries.

Overexploitation of wild species populations is the result of harvesting or killing animals or plants, for food, materials or medicine, over and above the reproductive capacity of the population to replace itself. It has been the dominant threat to marine biodiversity, and overfishing has devastated many commercial fish stocks, but overexploitation is also a serious threat to many terrestrial species, particularly among tropical forest mammals hunted for meat. Overharvesting of timber and fuelwood has also led to loss of forests and their associated plant and animal populations.

Invasive species, which have been introduced either deliberately or inadvertently from one part of the world to another and become competitors, predators or parasites of indigenous species, are responsible for declines in many native species populations. This is especially important on islands and in freshwater ecosystems, where they are thought to be the main cause of extinction among endemic species.

Pollution is another important cause of biodiversity loss, particularly in aquatic ecosystems. Excess nutrient loading is a result of the increasing use of nitrogen and phosphorous fertilizers in agriculture, which causes eutrophication and oxygen depletion. Toxic chemical pollution often arises from pesticide use in farming or aquaculture, from industry or mining wastes. One result of increasing carbon dioxide concentrations in the atmosphere is the acidification of the oceans, which is likely to have widespread effects on marine species, particularly shell- and reef-building organisms.

Less significant in the past, but with the potential to become the greatest threat to biodiversity over the course of the next few decades, is climate change. Already, impacts of climate change have been measured in arctic and alpine as well as coastal and marine ecosystems, such as coral reefs. The global extent of climate change will mean that no ecosystem on the surface of the Earth will be immune from rising air or sea temperatures or changing weather patterns.

It is clear that all of these direct threats or pressures are the effect, in turn, of more distant, indirect drivers of biodiversity loss which relate to the consumption of resources and pollution arising from their waste products. The ultimate drivers of threats to biodiversity are the human demands for food, water, energy and materials. These can be considered, sector by sector, in terms of the production and consumption of agricultural crops, meat and dairy products, fish and seafood, timber and paper, water, energy, transport, and land for towns, cities and infrastructure. As the human population and global economy grow, so do the pressures on biodiversity. The Ecological Footprint is a measure of the aggregate demands that the consumption of these resources places on natural ecosystems and species. Understanding the linkages and interactions between biodiversity, the drivers of biodiversity loss and the human footprint is fundamental to slowing, halting and reversing the ongoing declines in natural ecosystems and populations of wild species.

**BEYOND 2010**

By opting for a target to reduce the rate of biodiversity loss, the signatory nations conceded that halting the decline by 2010 is probably unachievable. With only two years to go, unless immediate action is taken to reduce the growing pressures on natural ecosystems, the loss of global biodiversity is set to continue unabated.

Whether or not we are on track to achieve the 2010 target, it is not too soon to start thinking about subsequent targets. Any future goals must be measured using indicators of the state of global biodiversity, the drivers and pressures causing its decline, and the societal impacts and responses to biodiversity loss. Indicators must be relevant, cost-effective and easily communicated, and any new targets should be measurable using those indicators.

Only a tiny fraction of all biomes, ecosystems and species are being monitored. The range of biodiversity that is covered by the existing indicators is far from complete, and we are particularly ignorant concerning tropical ecoregions, marine and freshwater biomes, and invertebrates. Addressing these knowledge gaps is essential.

Only by monitoring the state of global biodiversity, the drivers that affect it, and the impact of interventions designed to protect it, will we be able to identify and implement the most cost-effective and efficient responses to biodiversity loss.
### Biodiversity Loss, Human Pressure and the Ecological Footprint

#### Threats or Pressures

<table>
<thead>
<tr>
<th>HABITAT LOSS</th>
<th>DIRECT PRESSURES ON BIODIVERSITY</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Forest, woodland and mangrove loss and fragmentation</td>
</tr>
<tr>
<td></td>
<td>Grassland and savannah loss and degradation</td>
</tr>
<tr>
<td></td>
<td>River fragmentation and regulation</td>
</tr>
<tr>
<td></td>
<td>Coral reef and coastal habitat destruction</td>
</tr>
<tr>
<td></td>
<td>Benthic habitat destruction</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>OVEREXPLOITATION</th>
<th>DIRECT PRESSURES ON BIODIVERSITY</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Overfishing</td>
</tr>
<tr>
<td></td>
<td>Marine bycatch</td>
</tr>
<tr>
<td></td>
<td>Overharvesting terrestrial species</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>POLLUTION</th>
<th>DIRECT PRESSURES ON BIODIVERSITY</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Nutrient loading/eutrophication and toxic blooms</td>
</tr>
<tr>
<td></td>
<td>Acid rain</td>
</tr>
<tr>
<td></td>
<td>Pesticides and toxic chemicals</td>
</tr>
<tr>
<td></td>
<td>Oil spills</td>
</tr>
<tr>
<td></td>
<td>Ocean acidification</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>INVASIVE ALIEN SPECIES</th>
<th>DIRECT PRESSURES ON BIODIVERSITY</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Marine invasive species</td>
</tr>
<tr>
<td></td>
<td>Freshwater invasive species</td>
</tr>
<tr>
<td></td>
<td>Terrestrial invasive species, esp. on small islands</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>CLIMATE CHANGE</th>
<th>INDIRECT DRIVERS OF BIODIVERSITY LOSS/HUMAN ACTIVITIES</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Timber, pulp and paper production</td>
</tr>
<tr>
<td></td>
<td>Fuelwood collection</td>
</tr>
<tr>
<td></td>
<td>Conversion to cropland</td>
</tr>
<tr>
<td></td>
<td>Conversion to grazing land</td>
</tr>
<tr>
<td></td>
<td>Conversion to aquaculture</td>
</tr>
<tr>
<td></td>
<td>Conversion to urban land and road building</td>
</tr>
<tr>
<td></td>
<td>Dam building</td>
</tr>
<tr>
<td></td>
<td>Trawler fishing</td>
</tr>
<tr>
<td></td>
<td>Line fishing</td>
</tr>
<tr>
<td></td>
<td>Bushmeat hunting</td>
</tr>
<tr>
<td></td>
<td>Wildlife trade</td>
</tr>
<tr>
<td></td>
<td>Nitrogen and sulphur emissions</td>
</tr>
<tr>
<td></td>
<td>Organic waste</td>
</tr>
<tr>
<td></td>
<td>Agrochemical use</td>
</tr>
<tr>
<td></td>
<td>Mining waste and contamination</td>
</tr>
<tr>
<td></td>
<td>Nitrogen and sulphur emissions</td>
</tr>
<tr>
<td></td>
<td>Organic waste</td>
</tr>
<tr>
<td></td>
<td>Agrochemical use</td>
</tr>
<tr>
<td></td>
<td>Mining waste and contamination</td>
</tr>
<tr>
<td></td>
<td>Nitrogen and sulphur emissions</td>
</tr>
<tr>
<td></td>
<td>Organic waste</td>
</tr>
<tr>
<td></td>
<td>Agrochemical use</td>
</tr>
<tr>
<td></td>
<td>Mining waste and contamination</td>
</tr>
<tr>
<td></td>
<td>Nitrogen and sulphur emissions</td>
</tr>
<tr>
<td></td>
<td>Organic waste</td>
</tr>
<tr>
<td></td>
<td>Agrochemical use</td>
</tr>
<tr>
<td></td>
<td>Mining waste and contamination</td>
</tr>
<tr>
<td></td>
<td>Nitrogen and sulphur emissions</td>
</tr>
<tr>
<td></td>
<td>Organic waste</td>
</tr>
<tr>
<td></td>
<td>Agrochemical use</td>
</tr>
<tr>
<td></td>
<td>Mining waste and contamination</td>
</tr>
<tr>
<td></td>
<td>Nitrogen and sulphur emissions</td>
</tr>
<tr>
<td></td>
<td>Organic waste</td>
</tr>
<tr>
<td></td>
<td>Agrochemical use</td>
</tr>
<tr>
<td></td>
<td>Mining waste and contamination</td>
</tr>
<tr>
<td></td>
<td>Nitrogen and sulphur emissions</td>
</tr>
<tr>
<td></td>
<td>Organic waste</td>
</tr>
<tr>
<td></td>
<td>Agrochemical use</td>
</tr>
<tr>
<td></td>
<td>Mining waste and contamination</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>ECOLOGICAL FOOTPRINT/CONSUMPTION SECTORS</th>
<th>INDIRECT DRIVERS OF BIODIVERSITY LOSS/HUMAN ACTIVITIES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Timber, paper and fibre</td>
<td></td>
</tr>
<tr>
<td>Fuelwood</td>
<td></td>
</tr>
<tr>
<td>Food crops, oil crops, fibre crops</td>
<td></td>
</tr>
<tr>
<td>Meat, dairy, eggs, skins</td>
<td></td>
</tr>
<tr>
<td>Farmed fish and seafood</td>
<td></td>
</tr>
<tr>
<td>Construction, cement Mining and metals</td>
<td></td>
</tr>
<tr>
<td>Wild meat, fish and seafood</td>
<td></td>
</tr>
<tr>
<td>Domestic water</td>
<td></td>
</tr>
<tr>
<td>Industrial processing</td>
<td></td>
</tr>
<tr>
<td>Transport</td>
<td></td>
</tr>
<tr>
<td>Trade</td>
<td></td>
</tr>
<tr>
<td>Tourism</td>
<td></td>
</tr>
<tr>
<td>Energy use</td>
<td></td>
</tr>
<tr>
<td>Fossil fuel combustion</td>
<td></td>
</tr>
</tbody>
</table>
THE GLOBAL LIVING PLANET INDEX

The Living Planet Index (LPI) is a measure of the state of the world’s biodiversity based on trends from 1970 to 2005 in nearly 4,000 populations of 1,477 vertebrate species. It is calculated as the average of three separate indices that measure trends in populations of 813 terrestrial species, 320 marine species and 344 freshwater species.

The index shows an overall decline over the 35-year period, as do each of the terrestrial, marine and freshwater indices individually (Figures 4, 5 and 6). The global LPI shows an overall decline from 1970 to 2005 of 27 per cent (Figure 1).

No attempt is made to select species on the basis of geography, ecology or taxonomy, so the LPI dataset contains more population trends from well-researched regions, biomes and species. In compensation, temperate and tropical regions are given equal weight within the terrestrial and freshwater indices, as are the four ocean basins within the marine LPI, with equal weight being given to each species within each region or ocean basin. An assumption is made that the available population time series data are representative of vertebrate species in the selected ecosystems or regions, and that vertebrates are a good indicator of overall biodiversity trends.

The terrestrial LPI is the average of two indices which measure trends in temperate and tropical species respectively, and shows an overall decline of 25 per cent between 1970 and 2005 (Figure 4). The marine LPI shows a decline of 28 per cent between 1970 and 2005, with a dramatic decline between 1995 and 2005 (Figure 5). Many marine ecosystems are changing rapidly under human influence, and one recent study estimates that more than 40 per cent of the world’s ocean area is strongly affected by human activities while few areas remain untouched (Halpern et al., 2008).

Freshwater ecosystems provide water, food and other ecological services essential to human well-being. In spite of only covering about 1 per cent of the total land surface of the Earth, inland waters are home to an enormous diversity of over 40,000 vertebrate species. The overall freshwater LPI fell by 29 per cent between 1970 and 2003 (Figure 6).

Figure 4: Terrestrial Living Planet Index. The terrestrial LPI represents average trends in 813 species (1,820 populations) and shows an overall decline of 25 per cent from 1970 to 2005. Two indices, for tropical and temperate regions, are aggregated with equal weighting to produce the terrestrial LPI.

Figure 5: Marine Living Planet Index. The marine LPI represents overall trends in 320 species (1,180 populations) and falls rapidly over the last ten years of the period. Four ocean basin indices are aggregated to produce the marine LPI.

Figure 6: Freshwater Living Planet Index. The freshwater LPI represents trends in 344 species (988 populations) and shows an overall decline of 29 per cent. Tropical and temperate regional indices are aggregated with equal weighting to produce the freshwater LPI.
Each region of the world shows varying trends in species populations, reflecting the differing anthropogenic and environmental pressures on biodiversity. The terrestrial LPI reveals a marked difference in trends between tropical and temperate species (Figure 7). Tropical terrestrial species populations appear to have declined by 46 per cent on average between 1970 and 2005, while temperate species showed little overall change. Because of insufficient data on freshwater species populations, especially from the present decade, the freshwater indices have been calculated only to 2003 for temperate regions and to 2000 for tropical regions. The freshwater index for temperate regions declined by 26 per cent between 1970 and 2003, while the index for tropical regions fell by 35 per cent between 1970 and 2000 (Figure 8). These results do not necessarily imply that biodiversity in temperate regions is in a better state than it is in tropical regions: many declines among temperate species occurred before 1970 and so these trends are not reflected in this index. The rapid decline in tropical species is paralleled by a loss of natural habitat, particularly within tropical forest biomes.

Terrestrial and freshwater species were combined to give an indication of biodiversity trends within Europe, North America and Asia-Pacific – the regions with the most data available. Unfortunately, species population data from Latin America and Africa were insufficient to show overall trends for those continents as a whole with confidence, but data availability is improving and it is expected that it will be possible to make indices for these regions by 2010.

The European\(^1\) index shows an initial positive trend and then a decline since 1990, but there has been little absolute change since 1970 (Figure 9). The North American\(^2\) index shows no overall trend from 1970 to 2005. The Asia-Pacific\(^3\) region has undergone the greatest industrial and economic change over the last 20 years, and the index for this region displays the greatest decline in species population trends since the late 1980s.

Figure 7: Temperate and tropical terrestrial indices.

Figure 8: Temperate and tropical freshwater indices.

Figure 9: Regional terrestrial/freshwater indices.

![Figures showing trends in species populations over time](image)

---

\(^1\) Includes continental Europe as far as the Ural Mountains, plus Greenland, Iceland, Svalbard, Turkey, Georgia, Armenia and Azerbaijan.

\(^2\) Includes Canada and USA.

\(^3\) Includes continental Asia east of the Ural Mountains, the Middle East, South and Southeast Asia, and Australasia.
Marine Living Planet Indices

The global marine LPI is the average of four ocean basin indices (Figures 10 and 11), all of which show some decline in recent years to a greater or lesser extent. It is also possible to disaggregate global trends by species group as well as by region, and this has been done for marine fish and birds (Figure 12).

Species populations in the North Pacific and North Atlantic/Arctic Oceans show little or no absolute change from 1970 to 2005, although both ocean basin indices show a downward trend from about 1990 onwards (Figure 10). The indices of the southern hemisphere oceans are based on a smaller dataset than those of the northern hemisphere oceans. They reveal a long-term decline in the South Atlantic/Southern Ocean and a dramatic decline in the South Pacific/Indian Ocean since the mid-1990s (Figure 11), although with lower confidence than for the northern hemisphere. According to a recent assessment of pressures on marine ecosystems (Halpern et al., 2008), the North Sea, the East and South China Seas, the Bering Sea and much of the coastal waters of Europe, North America, the Caribbean, China and Southeast Asia are heavily impacted by fishing, invasive species, pollution and greenhouse gas emissions.

The marine fish index remained fairly level until about 1990 but subsequently dropped, indicating an overall fall in abundance of 21 per cent during the 35-year period (Figure 12).

The index for marine birds shows a positive trend from 1970 to the mid-1990s, but a rapid decline of about 30 per cent since the mid-1990s (Figure 12). This fall in bird populations may be the result of multiple threats, including bycatch from long-line fishing, pollution and the decline in abundance of marine fish as indicated by the marine fish index.

Southern Ocean and the South Pacific/Indian Ocean respectively. Both show severe declines over the three decades from 1970 to 2002.

Figure 10: Northern marine indices. These two indices show little or no overall change in abundance over the period 1970–2005, although both show a downward trend since the mid-1990s. The indices are based on populations of 185 and 84 species from the North Atlantic/Arctic Ocean and North Pacific Ocean respectively.

Figure 11: Southern marine indices. These two indices represent trends in 48 and 52 marine species from the South Atlantic/

Figure 12: Marine fish and bird indices. The marine fish index shows an average decline in abundance of 21 per cent across 145 species of marine fish between 1970 and 2005, whereas the trend in 120 species of marine birds shows an overall fall of 14 per cent over the same period, but with a steeper drop since the mid-1990s.
Trends in sample populations of selected species

- **Green turtle (Chelonia mydas), Costa Rica**
  - 1970: Estimated no. of nests: 130
  - 2005: No. of active nests: 250

- **Common snipe (Gallinago gallinago), Sweden**
  - 1970: Annual population index: 130
  - 2005: No. of active nests: 250

- **Chimpanzee (Pan troglodytes), Côte d'Ivoire**
  - 1970: No. of individuals: 30
  - 2005: No. of individuals: 40

- **White-rumped vulture (Gyps bengalensis), India**
  - 1970: No. of individuals: 500
  - 2005: No. of individuals: 50

- **Amur tiger (Panthera tigris), Russia**
  - 1970: No. of individuals: 50
  - 2005: No. of individuals: 500

- **Baiji (Lipotes vexillifer), China**
  - 1970: No. of individuals: 7,000
  - 2005: No. of individuals: 40

- **Atlantic salmon (Salmo salar), Norway**
  - 1970: No. of fry per 100m²: 50
  - 2005: No. of fry per 100m²: 100

- **Scalloped hammerhead (Sphyrna lewini), United States of America**
  - 1970: No. of dens per 100km²: 10
  - 2005: No. of dens per 100km²: 100

- **Polar bear (Ursus maritimus), Russia**
  - 1970: Biomass (tonnes): 250
  - 2005: Biomass (tonnes): 300
The Ecological Footprint measures humanity’s demand on the biosphere in terms of the area of biologically productive land and sea required to provide the resources we use and to absorb our waste. In 2003 the global Ecological Footprint was 14.1 billion global hectares, or 2.2 global hectares per person (a global hectare is a hectare with world-average ability to produce resources and absorb wastes). The total supply of productive area, or biocapacity, in 2003 was 11.2 billion global hectares, or 1.8 global hectares per person.

The footprint of a country includes all the cropland, grazing land, forest and fishing grounds required to produce the food, fibre and timber it consumes, to absorb the wastes emitted in generating the energy it uses, and to provide space for its infrastructure.

People consume resources and ecological services from all over the world, so their footprint is the sum of these areas, wherever they may be on the planet.

Humanity’s footprint first grew larger than global biocapacity in the 1980s; this overshoot has been increasing every year since, with demand exceeding supply by about 25 per cent in 2003. This means that it took approximately a year and three months for the Earth to produce the ecological resources we used in that year.

Separating the Ecological Footprint into its individual components demonstrates how each one contributes to humanity’s overall demand on the planet. Figure 14 tracks these components in constant 2003 global hectares, which adjust for annual changes in the productivity of an average hectare. This
makes it possible to compare absolute levels of demand over time. The carbon dioxide (CO₂) footprint, from the use of fossil fuels, was the fastest-growing component, increasing more than ninefold between 1961 and 2003.

How is it possible for an economy to continue operating in overshoot? Over time, the Earth builds up ecological assets, like forests and fisheries. These accumulated stocks can, for a limited period, be harvested faster than they regenerate. CO₂ can also be emitted into the atmosphere faster than it is removed, accumulating over time.

For three decades now we have been in overshoot, drawing down these assets and increasing the amount of CO₂ in the air. We cannot remain in overshoot much longer without depleting the planet’s biological resources and interfering with its long-term ability to renew them.

Figure 13: Ecological Footprint per person, by country. This includes all countries with populations greater than 1 million for which complete data are available.

Figure 14: Ecological Footprint by component. The footprint is shown in constant 2003 global hectares. In both diagrams, hydropower is included in the built-up land footprint and fuelwood within the forest footprint. For additional information about the Ecological Footprint methodology, data sources, assumptions and definitions (including revisions to the UAE footprint), please visit www.footprintnetwork.org/2006technotes.
BIODIVERSITY – BUILDING SECURITY FOR THE FUTURE

Food, clean water, medicines and protection from natural hazards are important ingredients in maintaining our security and quality of life. Can we guarantee their continued availability? The answer is “yes” – but only if we conserve the biodiversity that underpins the natural habitats and ecosystems which, in turn, support them. The global community recognized the need to conserve biodiversity in 2002 when governments committed to achieving “a significant reduction of the current rate of biodiversity loss” by 2010. But this report clearly shows that this target is unlikely to be met, with biodiversity continuing to be lost.

Protecting biodiversity – the genetic pool, the extent and variety of species and ecosystems – is critical to maintaining and improving the quality of life of the world’s people.

Neglecting biodiversity invites crop collapse, thirst, disease and disaster.

The degradation of ecosystems has already taken us to new levels of vulnerability – and climate change is intensifying this. As ecosystems are degraded, species are lost and key natural services fail. Humanity is already incurring the costs of biodiversity loss, which are disproportionately borne by poor people and nations, but which also scale income levels and cross borders.

FOOD SECURITY
Of the 75,000 or so edible plant species, only around 150 are widely cultivated, just three of which provide 50 per cent of our food. In humanity’s drive to feed an ever-growing population, we have become dependent on a few high-yielding varieties of these crops.

The maintenance of biodiversity, however, is key to ensuring we have crops that can withstand diseases and a changing climate. Traditional varieties and the wild relatives of commercial crops provide a critical reserve of genes that are regularly needed to strengthen and adapt their modern domestic cousins in a changing world. Allowing these to become extinct on farms or in the wild endangers food security. Yet research suggests that the world’s centres of crop diversity remain inadequately protected, and that we may have already eradicated three-quarters of the planet’s agricultural crop genetic diversity.

We are also failing to look after our ocean harvests. The annual catch of the global fishing industry is worth US$70–80 billion, with around 500 million people relying on fish as their principal source of animal protein.

But the current fish catch is unsustainable. According to the Food and Agriculture Organization of the United Nations, more than 50 per cent of global fish stocks are fully exploited and 25 per cent overexploited, depleted or recovering from depletion. Some fisheries have already collapsed, and others are predicted to do so. According to some scientists, commercial fishing will no longer be viable by 2048. Yet, despite the role that marine protected areas can play in replenishing stocks, less than 1 per cent of the marine environment is protected.

When countries made the commitment to protect one-tenth of ecosystem types by 2010, they were, in part, agreeing to ensure future food supplies. But more systematic identification and protection of the places containing wild crop relatives and of key breeding and nursery areas for fish stocks are needed to secure the future food supply for a growing population.

WATER SUPPLY
Exploitation of the planet’s freshwater is increasing to the extent that, by 2030, nearly half the world’s population will be facing water shortages. Rivers have been dammed and diverted, and wetlands drained – all impacting freshwater ecosystems and species. Forest clearance, climate change, pollution and inefficient water use, combined with the global commitment to supply increasing numbers of people with a reliable supply of freshwater sufficient to meet their needs, are putting such pressure on water systems that only

FACTS ON WATER SECURITY
- Natural or semi-natural habitats can help to mitigate flooding.
- Protected areas can provide barriers against the impacts of drought and desertification.
- Freshwater species are thought to be some of the most threatened. A third of all freshwater species that have been assessed are threatened with extinction, and populations of freshwater species have declined by 30 per cent overall.
- Over 30 per cent of the world’s largest cities rely directly on protected areas for their drinking water. A further 10 per cent obtain their water from sources that originate in “protected” watersheds, i.e. that include protected areas, or from forests that are managed in a way that prioritizes their water-securing functions.
- The economic value of watersheds is almost always underestimated or unrecognized.
- On top of the current 1.4 billion people living in water-stressed areas, by 2050, a further 700 million to 2.8 billion people are expected to face increased water shortages.

FACTS ON FOOD SECURITY
- Populations of teosinte, the closest wild relative of maize, shrank by more than 50 per cent in the last 40 years in Central America.
- 75 per cent of rice varieties grown in Sri Lanka are descendants from one parent plant.
- Global fishing fleets are estimated to have a capacity 250 per cent greater than sustainable available catches.
- 75 per cent of global fish stocks are fully used, overused or in crisis.
use of these medicinal plants. Both protect and provide for the sustainable maintenance this natural pharmacy it is vital to plants forming the primary ingredients. To develop countries rely on herbal remedies and medicines for their health care, with wild An estimated 80 per cent of people in HUMAN HEALTH natural filtration and aquifer replenishment. reservoirs, providing efficient water collection, infrastructure – are the most economic water supply, medicine and disaster mitigation. However, forests – a natural catchment are the most economic rehydration tool, yet currently are not the instrument of choice for enough of our centres population. Carefully located and managed, protected forest areas can act as natural reservoirs, educating efficient water collection, natural filtration and aquifer replenishment.

HUMAN HEALTH An estimated 80 per cent of people in developing countries rely on herbal remedies and medicines for their health care, with wild plants forming the primary ingredients. To maintain this natural pharmacy it is vital to both protect and provide for the sustainable use of these medicinal plants.

The pharmaceutical industry also relies on biodiversity. In 2002–2003, four-fifths of new chemicals introduced globally as drugs were inspired by natural products. But without systems and mechanisms that can conserve the diversity of life on Earth, how many potential cures will be lost as biodiversity is eroded?

The development of an international regime under the Convention on Biological Diversity for the equitable sharing of benefits from the use of genetic resources could benefit people in developing and developed countries alike. These benefits would provide a major incentive for the conservation of biodiversity and traditional knowledge, while in the longer term helping to ensure the health of all.

FACTS ON DISASTER MITIGATION

- Centuries ago, restoration of forests in the watershed above Malaga, Spain, ended the flooding that had been recorded at regular intervals over 500 years.
- In the Seychelles, wave energy has doubled as a result of sea-level rise, loss of coral reefs and changes to reef make-up. Models predict that wave energy will double again in the next decade due to further reef damage.
- Philippines President Gloria Arroyo blamed indiscriminate logging, which has left the country with less than 6 per cent of its original forest, for flash floods and landslides that left over 1,600 people dead or missing in 2004.

The true protection of biodiversity can only happen through cross-sectoral action. From ministries of finance, health, agriculture and food to leaders of business and industry, producers and consumers, all have a role to play. Our efforts must be directed towards sustainability: of our food and water, our medicines, our economies and our existence.

RECOMMENDATIONS

WWF calls on governments to:

1. Develop joint biodiversity protection implementation plans between environment, agriculture, food, water, finance and health ministries in order to take urgent action to reduce the rate of biodiversity loss by 2010.

2. Urgently implement the Convention on Biological Diversity Programme of Work on Protected Areas prioritizing the protection of areas that are important for food security, water supply, medicine and disaster mitigation.

3. Implement incentive and financing measures that support the establishment and maintenance of protected areas.

4. Accelerate the development and adoption of an international regime on the equitable sharing of benefits from the utilization of genetic resources by 2010.

5. Take account of the true cost of ecosystem services in national budgets and adopt national indicators that measure the state of biodiversity and pressures on natural ecosystems.
Global Living Planet Index

The species population data used to calculate the LPI are gathered from a variety of sources in scientific journals, NGO literature and online. All data were used in constructing the index are time series of either population size or a proxy of population size. The terrestrial and marine datasets comprise data from 1960 to 2005 and the freshwater dataset from 1960 to 2003 owing to fewer numbers of time series from recent years. Generalized additive modelling was used to determine the underlying trend in each population time series. These were then used to calculate the average rate of change in each year across all species. All indices were calculated using population data from 1960 to 2005, or the most recent year for which data were available, and set equal to 1.0 in 1970 (pre-1970 trends are not shown). The global LPI was aggregated according to the hierarchy of indices shown in Figure 15. For further details please refer to Loh et al. (2005).

Regional indices

The indices for Europe and North America were aggregated by weighting two groups – bird species and all other vertebrate species – to reflect the actual species numbers in those groups from those regions (approximately 30 per cent are birds). This was because the data availability in Europe and North America is biased towards bird species (about 75 per cent of the data). This resulted in the mammal, fish, reptile and amphibian species representing equal weight within each species; each species carries equal weight within tropical and temperate realms or within each ocean basin; temperate and tropical realms, or ocean basins, carry equal weight within each system; each system carries equal weight within the overall LPI.

Figure 15: Hierarchy of indices within the Living Planet Index. Each population carri
equal weight within each species; each species carries equal weight within tropical and temperate realms or within each ocean basin; temperate and tropical realms, or ocean basins, carry equal weight within each system; each system carries equal weight within the overall LPI.

| Table 1: NUMBERS OF SPECIES WITHIN EACH SYSTEM AND VERTEBRATE CLASS |
|-----------------|-----------------|-----------------|-----------------|-----------------|
|                 | Terrestrial     | Freshwater      | Marine          | Total           |
| Fish            | 94              | 147             |                 | 241             |
| Amphibians      | 14              | 69              |                 | 83              |
| Reptiles        | 16              | 17              | 7               | 40              |
| Birds           | 538             | 153             | 120             | 811             |
| Mammals         | 245             | 11              | 46              | 302             |
| **Total**       | **813**         | **344**         | **320**         | **1 477**       |

Table 2: LIVING PLANET INDICES

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Global Living Planet Index</td>
<td>1.000</td>
<td>1.035</td>
<td>1.020</td>
<td>0.998</td>
<td>0.963</td>
<td>0.986</td>
<td>0.761</td>
<td>0.725</td>
</tr>
<tr>
<td>Terrestrial</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Global</td>
<td>1.000</td>
<td>1.045</td>
<td>1.002</td>
<td>0.944</td>
<td>0.896</td>
<td>0.864</td>
<td>0.763</td>
<td>0.749</td>
</tr>
<tr>
<td>Temperate</td>
<td>1.000</td>
<td>0.980</td>
<td>0.995</td>
<td>0.976</td>
<td>1.004</td>
<td>1.026</td>
<td>1.052</td>
<td>1.059</td>
</tr>
<tr>
<td>Tropical</td>
<td>1.000</td>
<td>1.114</td>
<td>1.008</td>
<td>0.913</td>
<td>0.800</td>
<td>0.727</td>
<td>0.554</td>
<td>0.540</td>
</tr>
<tr>
<td>Freshwater</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Global</td>
<td>1.000</td>
<td>1.027</td>
<td>1.070</td>
<td>1.052</td>
<td>0.946</td>
<td>0.802</td>
<td>0.678</td>
<td>–</td>
</tr>
<tr>
<td>Temperate</td>
<td>1.000</td>
<td>1.104</td>
<td>1.178</td>
<td>1.160</td>
<td>1.051</td>
<td>0.881</td>
<td>0.707</td>
<td>–</td>
</tr>
<tr>
<td>Tropical</td>
<td>1.000</td>
<td>0.956</td>
<td>0.972</td>
<td>0.954</td>
<td>0.851</td>
<td>0.730</td>
<td>0.650</td>
<td>–</td>
</tr>
<tr>
<td>Regional terrestrial/freshwater</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Europe</td>
<td>1.000</td>
<td>1.108</td>
<td>1.124</td>
<td>1.127</td>
<td>1.286</td>
<td>1.193</td>
<td>0.980</td>
<td>0.821</td>
</tr>
<tr>
<td>North America</td>
<td>1.000</td>
<td>0.867</td>
<td>0.916</td>
<td>0.904</td>
<td>0.879</td>
<td>0.855</td>
<td>0.774</td>
<td>1.010</td>
</tr>
<tr>
<td>Asia-Pacific</td>
<td>1.000</td>
<td>1.110</td>
<td>1.157</td>
<td>1.132</td>
<td>1.022</td>
<td>0.750</td>
<td>0.519</td>
<td>0.227</td>
</tr>
<tr>
<td>Marine</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Global</td>
<td>1.000</td>
<td>1.032</td>
<td>0.991</td>
<td>1.001</td>
<td>1.053</td>
<td>1.003</td>
<td>0.850</td>
<td>0.722</td>
</tr>
<tr>
<td>North Atlantic/Arctic Ocean</td>
<td>1.000</td>
<td>1.073</td>
<td>1.140</td>
<td>1.142</td>
<td>1.175</td>
<td>1.174</td>
<td>1.172</td>
<td>0.946</td>
</tr>
<tr>
<td>North Pacific Ocean</td>
<td>1.000</td>
<td>1.111</td>
<td>1.165</td>
<td>1.322</td>
<td>1.374</td>
<td>1.227</td>
<td>1.100</td>
<td>1.096</td>
</tr>
<tr>
<td>South Pacific/Indian Ocean</td>
<td>1.000</td>
<td>0.906</td>
<td>1.033</td>
<td>1.074</td>
<td>1.098</td>
<td>1.010</td>
<td>0.798</td>
<td>–</td>
</tr>
<tr>
<td>South Atlantic/Southern Ocean</td>
<td>1.000</td>
<td>1.052</td>
<td>0.702</td>
<td>0.621</td>
<td>0.694</td>
<td>0.694</td>
<td>0.507</td>
<td>–</td>
</tr>
<tr>
<td>Birds</td>
<td>1.000</td>
<td>1.035</td>
<td>1.091</td>
<td>1.130</td>
<td>1.246</td>
<td>1.197</td>
<td>1.061</td>
<td>0.861</td>
</tr>
<tr>
<td>Fish</td>
<td>1.000</td>
<td>1.088</td>
<td>1.062</td>
<td>1.048</td>
<td>1.042</td>
<td>0.943</td>
<td>0.912</td>
<td>0.788</td>
</tr>
</tbody>
</table>
Table 3: INDEX VALUES WITH 95% CONFIDENCE LIMITS

<table>
<thead>
<tr>
<th>Species</th>
<th>No. of Change (%)</th>
<th>Lower</th>
<th>Upper</th>
</tr>
</thead>
<tbody>
<tr>
<td>Global Living Planet Index</td>
<td>1,477</td>
<td>-27</td>
<td>-37</td>
</tr>
<tr>
<td>Terrestrial</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Global</td>
<td>813</td>
<td>-25</td>
<td>-37</td>
</tr>
<tr>
<td>Tropical</td>
<td>591</td>
<td>3</td>
<td>-3</td>
</tr>
<tr>
<td>Freshwater</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Global</td>
<td>344</td>
<td>-29</td>
<td>-43</td>
</tr>
<tr>
<td>Temperate</td>
<td>293</td>
<td>-26</td>
<td>-39</td>
</tr>
<tr>
<td>Tropical</td>
<td>57</td>
<td>-35</td>
<td>-55</td>
</tr>
<tr>
<td>Regional terrestrial/freshwater</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Europe</td>
<td>276</td>
<td>-12</td>
<td>1</td>
</tr>
<tr>
<td>North America</td>
<td>576</td>
<td>-1</td>
<td>-</td>
</tr>
<tr>
<td>Asia-Pacific</td>
<td>165</td>
<td>-77</td>
<td>-88</td>
</tr>
<tr>
<td>Marine</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Global</td>
<td>320</td>
<td>-28</td>
<td>-47</td>
</tr>
<tr>
<td>North Atlantic/Arctic Ocean</td>
<td>185</td>
<td>-5</td>
<td>-33</td>
</tr>
<tr>
<td>South Atlantic/Southern Ocean</td>
<td>48</td>
<td>-46</td>
<td>-70</td>
</tr>
<tr>
<td>North Pacific</td>
<td>84</td>
<td>10</td>
<td>-23</td>
</tr>
<tr>
<td>South Pacific/Indian Ocean</td>
<td>52</td>
<td>-53</td>
<td>-81</td>
</tr>
<tr>
<td>Birds</td>
<td>120</td>
<td>-14</td>
<td>-40</td>
</tr>
<tr>
<td>Fish</td>
<td>145</td>
<td>-21</td>
<td>-41</td>
</tr>
</tbody>
</table>


REFERENCES


WWF WORLDWIDE NETWORK

Australia | Germany |
Belgium | Greater Mekong (Viet Nam) |
Bhutan | Greece |
Bolivia | Guianas (Suriname) |
Brazil | Hong Kong |
Canada | Hungary |
Caucasus (Georgia) | India |
Central Africa | Indonesia |
(Cameroun) | Italy |
Central America (Costa Rica) | Japan |
China | Madagascar |
Colombia | Malaysia |
Danube-Carpathian (Austria) | Mediterranean (Italy) |
Denmark | Mexico |
Eastern Africa (Kenya) | Mongolia |
Finland | Nepal |
France | Netherlands |
Norway | New Zealand |
Pakistan | Arctic Programme |
Peru | European Policy |
Philippines | (Belgium) |
Poland | Macroeconomics |
Russia | for Sustainable Development (USA) |
South Africa | Singapore |
Southern Africa | WWF ASSOCIATES |
(Zimbabwe) | Fundación Vida Silvestre |
(Argentina) | Fundación Natura |
Spain | (Ecuador) |
Sweden | Pasuales Dabas Fonds |
Switzerland | (Latvia) |
Tanzania | Nigerian Conservation Foundation (Nigeria) |
Turkey | United Kingdom |
United States | United States |
Western Africa (Ghana, Senegal) |
WWF's mission is to stop the degradation of the planet’s natural environment and to build a future in which humans live in harmony with nature, by:
- conserving the world’s biological diversity
- ensuring that the use of renewable natural resources is sustainable
- promoting the reduction of pollution and wasteful consumption.
Biological diversity, or biodiversity for short, encompasses the variety of life at all levels of organization, from genetic diversity within a species to diversity within entire regions or ecosystems. Biodiversity is increasingly recognized as critical to human life, but many species are more threatened than ever by urbanization, global deforestation, climate change, overexploitation of the world’s fisheries and marine ecosystems, industrial agricultural expansion and other human activities.

Why Is Biodiversity Important?

The diversity of life on our planet is critical for maintaining the basic planetary life support systems we rely on every day. Ecosystem services, or the resources nature provides us free of charge, like drinking water, crop pollination, nutrient cycling and climate regulation, all rely on biodiversity. For instance, the diversity of insect and avian pollinators is crucial to global agricultural productivity, ensuring plants produce harvestable crops for human use.

The Earth’s staggering biodiversity is also responsible for more tangible human goods. In many parts of the world, plants are the main source of medicine used for primary health care, linking the survival of plant diversity with human well-being. Additionally, many of our most important pharmaceutical drugs come from compounds discovered only in specific plants or organisms, meaning future drug discoveries may well depend on the survival of species that have yet to be studied for their medicinal properties.

Biodiversity and Agriculture

Farmers rely on services provided by ecosystems to produce the foods we eat every day, and the health of ecosystems, in turn, are dependent on biodiversity. The relationship between agriculture and biodiversity can be understood in two ways—first, as the biodiversity within farmland landscapes (i.e. the biodiversity of soil microbes, birds, insects, etc.) and also as the biodiversity of agricultural crops and animals, or agrobiodiversity (i.e. breeds of cattle, varieties of wheat, etc.).

Biodiversity in the agricultural landscape.

Biodiversity is important at all scales of the agricultural landscape. From billions of different soil microbes that help cycle nutrients and decompose organic matter, to wasps and bats that help reduce crop pests, to birds and insects that pollinate high value crops,
biodiversity helps farmers successfully grow food and maintain sustainable farm landscapes.

For example, although many of our most important crops are wind-pollinated and do not require pollinators, 39 of the leading 57 global crops benefit from natural pollinators, such as birds and insects. A striking example of our dependence on pollinator services and the damage that can be inflicted on the agricultural economy without them can be seen in the decline of US honeybee populations beginning in late 2006 which became known as Colony Collapse Disorder (CCD). Although scientific debate continues on the ultimate causes of CCD, honeybee declines have served as an important wakeup call to protect both our managed and wild pollinator species.

But not only does the maintenance of biodiversity help ensure viable crop production, many organisms and species have come to rely on particular agricultural landscapes for their very survival. As an example, farmland bird biodiversity in Europe has declined dramatically in the past two decades as a result of the intensification and industrialization of Europe’s farmland and agriculture practices. In sum, agriculture both supports, and is supported by, the maintenance of biodiversity.

**Agrobiodiversity**

Agrobiodiversity refers to biodiversity among planned agricultural crops or livestock, such as the genetic diversity of wheat varieties or cattle breeds. Agrobiodiversity is the result of thousands of years of human intervention in selectively breeding traits in animals and crops for particular agricultural advantages. A famous example of the diversity that can exist within one crop species is found in the diversity of potatoes grown in the Andes of South America, where potatoes originated and some 4,000 known varieties, or landraces, exist. This abundance of diversity is the result of farmers artificially selecting traits over generations for specific purposes, like resistance to disease, tolerance to high altitudes or poor soils, etc. This diversity is important for food security—in the event that a particular crop variety fails due to drought, flooding or a disease, another variety might survive to avoid food shortages. In stark contrast to this model of agrobiodiversity, the Irish Potato Famine of the 1840s was the result of a fungus that completely destroyed the Irish potato crop because only a few varieties of potatoes had been imported from the Andes to Europe, none of which were resistant to the disease. Because of a lack of crop diversity and overreliance on one crop to feed many of its population, Ireland experienced widespread famine and death.

**Biodiversity and the Modern Industrial Food System**

Diminishing agrobiodiversity is not only a historical problem, however. The FAO has estimated that during the last century, 75 percent of crop genetic diversity has been lost, a phenomenon referred to as genetic erosion. This loss of genetic diversity in plant crops and animal breeds is dangerous because it makes our food supply more vulnerable to outbreaks of pests and disease. For instance, in the 1970s, a lack of genetic diversity in US corn varieties resulted in the loss of over 1 billion US dollars due to a lack of resistance to leaf blight. Unfortunately, the situation has not improved today, as increasingly, industrial food production relies on fewer and fewer crop varieties and animal breeds, further imperiling the security of our food system.

As mentioned earlier, industrial agriculture can reduce biodiversity by also diminishing biodiversity in the wider agricultural landscape. Excessive manure, nutrient and pesticide runoff from industrial animal and plant agriculture can all negatively impact both aquatic and terrestrial ecosystems and the biodiversity they support. Nutrient runoff can cause eutrophication of bodies of water like rivers and streams, in some cases literally suffocating fish and other organisms, resulting in mass die-offs. Pesticide runoff has been implicated in reducing biodiversity within agricultural landscapes both within terrestrial and aquatic landscapes, a famous example being the near eradication of a number of US bird species from the use of the insecticide DDT during the second half of the 20th Century.

A major cause of farmland biodiversity declines in the last century is the simplification of the modern industrial agriculture landscape. In previous centuries, farmland agroecosystems were diverse mixes of grazing land, crop land, orchards, wetlands and managed forests, which could support a wide array of biological diversity. Today, however, most industrial agriculture landscapes plant crops “fencerow to fencerow,” meaning the amount of harvestable land is maximized for the greatest profits, which has resulted in a reduction of the diversity of agricultural landscapes, in turn reducing agroecosystem biodiversity.
Native American Gardening: The Three Sisters and More

Connect to an ancient heritage by growing these rare vegetable varieties traced back to Native American gardens. February/March 2013

http://www.motherearthnews.com/organic-gardening/vegetables/native-american-gardening-zm0z13fmzsto

By William Woys Weaver

The concept of companion planting, in which one plant helps the other, is the basic idea behind the Three Sisters, but focusing on this alone glosses over many of the nuances in native garden traditions.

Photo By Rob Cardillo Photography

Considering how corn, beans, squash and other “New World” foods have changed the course of human culture, the time is ripe to take a fresh look at Native American gardening. Here, within easy reach, is one of the greatest horticultural treasures — a system of gardening that is, by definition, an icon of biodiversity. Offering a rich array of unusual tastes and textures, the Native American garden is part and parcel of what I consider the “soul” of American food. And yet the full story is not exactly a happy one.

Years ago, I had the pleasure of chatting with the late Gladys Tantaquidgeon (1899-2005), a Mohegan anthropologist with whom I discussed some of the pressing issues facing Native American gardening. She expressed frustration about Mohegan garden seeds not being preserved during the 19th century, and how this loss is reflected by what Mohegans — tribespeople from upstate New York and later Connecticut — grow in their gardens today.

Chief James “Lone Bear” Revey (1924-1998) of the N.J. Sand Hill Band of the Delaware Nation also devoted many hours to passionate discussion with me on the seed losses taking place among his people. The causes have been many — inroads of changing lifestyles, poverty, government programs forcing native peoples into a mainstream mold, the loss of foodways and native religions — and the results have at times been devastating. But much has survived. There are perhaps two distinct Native American gardens: the stereotypical one many of us envision, consisting of just the “Three Sisters” (corn, beans and squash), and a more complex one that served not only as a source of food for native peoples, but was also an extension of their religions. For many tribes, each plant was assigned a specific spiritual role, and each part of the plant (the roots, stems, leaves and flowers, as well as the fruits) was imbued with deep meaning and a role in native healing practices.

Reproducing a Native American garden isn’t easy, which is why I’d like to make this a clarion call to find a way to preserve this heritage. This imperative is especially urgent given the spread of genetically modified corn and the radical manner in which it has transformed corn from the nurturing “mother” of Native American culture into a largely inedible, industrial material. The innate spirituality of this graceful plant has been grossly denatured. Planting a Native American garden is a rewarding way to recapture this connection with the Earth.
The Real Three Sisters Garden

The concept of companion planting, in which one plant helps the other, is the basic idea behind the Three Sisters, but focusing on this alone glosses over many of the nuances in native garden traditions. Growing plants to work together symbiotically — using hills of corn to serve as poles for beans, and interplanting this with squash to keep down invasive weeds — is as much about compatibility and harnessing nature to do part of the work as it is a study in what we take from nature and what we give back. Like strip mining, modern agribusiness is based on yields extracted from the land regardless of the environmental cost. The Native American garden, which was actually a form of small-scale farming, made the land richer — one reason why early settlers were eager to seize Native American fields.

Some of the earliest illustrations that have survived of Native American fields — depictions of patches of corn and squash from the 1580s — show no evidence of Three Sisters gardening. They do show a clear understanding of the separation of corn varieties so they tassel at different times and thus do not cross-pollinate. Some native peoples farmed with other mixes of plants. The Hopi introduced a fragrant wildflower into their gardens to attract pollinators. Other peoples intermingled their corn and beans with sunflowers, which make wonderful “poles” for beans that grow too tall to climb up cornstalks.

Native American gardens were fine-tuned to their local micro-climate, and this is a feature often overlooked by gardeners today. One seed does not fit all gardens. Native peoples maintained a wide selection of plants because they often moved around, so what may have worked well in North Carolina among the Cherokee may not have been successful on the Great Plains. The Pawnee of the Midwest, for example, maintained four sacred corn varieties, of which their white-flour corn, called “Mother Corn,” was the most highly venerated. If one failed, they had others they could rely on.

Native American Corn

Native corns are heartier and generally more drought-resistant and adaptable than modern-day industrial varieties. Choosing the right corn to grow in your region is important, especially because the corn more or less serves as the “framework” for a Native American garden. If you plan to save seed for next year, choose one variety of corn to grow at a time in a given area to prevent cross-pollination.

Pure strains of native corns are difficult to distinguish unless they’ve been carefully grown in isolation, such as those sold by Native Seeds/SEARCH, a nonprofit headquartered in Tucson, Ariz. Some Native American cultural museums sell seeds connected with their cultures, and Seed Savers Exchange in Decorah, Iowa, has many members who offer seeds in its annual yearbook that are believed to have come from Native American sources.

I have been growing native corns for many years and recently began large-scale grow-outs at Mill Hollow Farm near Edgemont, Pa. Two corns in particular — ‘Tutelo Strawberry’ (a short-eared flint) and ‘Delaware Indian Puhwem’ (flour corn) — have done extremely well, and seeds are available directly from the farm (see the chart key in Seed Varieties for Your Native American Garden (http://www.motherearthnews.com/organic-gardening/native-american-garden-zm0z13fmzsto.aspx)). In the future, I plan to offer some Seneca corns, particularly ‘Ha-Go-Wa’ (hominy corn) and ‘Blue Bear Dance,’ as well as ‘Tuscarora’ flour corn.

Native American Squash and Beans

Locating authentic Native American squash for your garden will prove extra challenging, because many of the squash varieties have been “improved” over the years by plant breeders looking for characteristics that
appeal to present-day cooks. ‘Early White Scallop’ and ‘Yellow Summer Crookneck’ are examples of this kind of improved plant stock. While both can be documented to the 18th century and earlier, they are somewhat different from the Native American originals. The old-style plants were vining rather than bush in habit, for example.

Aside from pattypan squash, finger squash and a few others, not many varieties of squash and pumpkins have survived from early Native American gardens, especially in the eastern part of the United States. I have been involved in a project in my own garden to recover Nanticoke “maycocks,” an old native name for summer squash eaten green. These squash probably represent a range of what native peoples were looking for in squash, as some are good for cooking fresh, some for drying, some for seed oil, and some for long-term storage.

There are a great many Native American beans, but few of them are preserved under their original Native American names. After quite a bit of research and some luck, I discovered that the meaty ‘Ohio Pole Bean’ — a favorite of mine — was actually an old variety grown by the Delaware, Potawatomi, Shawnee and Miami living in the vicinity of Ft. Wayne, Ind., in the 1790s. The ‘Amish Nuttle’ bean is another Native American variety that has come down to us under several non-native names. The chart in Seed Varieties for Your Native American Garden (http://www.motherearthnews.com/organic-gardening/native-american-garden-zm0z13fmzsto.aspx) has many more recommended varieties.

Planting Techniques

Planting your Native American garden is relatively easy after you have chosen a plot of ground and prepared it. The Native American garden was not like a European kitchen garden, but rather a small field, so if possible, you should think in terms of perhaps a quarter-acre. You’ll need that kind of space to produce enough corn for food and next year’s seed, because your corn should be planted in hills about 3 feet in diameter and spaced 4 feet apart in all directions. With four to six corn plants per hill, 30 or 40 hills will take up a lot of space, but you’ll also be able to plant several varieties of pole beans around the corn after the corn is about a foot tall. The beans’ role is to fix nitrogen in the soil, which is vital for successful corn production. You can grow several bean varieties without worrying about crosses as long as you plant one variety per hill of corn.

The best bean varieties for short corn (corn that grows about 6 feet tall), such as ‘Tutelo Strawberry,’ are the semi-pole or Native American bush beans that develop long runners — ‘Amish Nuttle’ or ‘Wild Pigeon’ are good examples. Taller corn can support beans with longer vines, but some pole beans are simply too aggressive for corn. Sunflowers are a good alternative here, and they can be planted at the cross section of the spaces between the corn hills. Squash with small leaves can be planted in between. Large, vigorous pumpkins were generally planted off by themselves, as they also like to climb and could pull down the corn. Around the edge of your little field is an ideal place to put Jerusalem artichokes — another Native American favorite. Other plants such as goosefoot and amaranth were allowed to come up among the squash, and these could be harvested both for greens and for seeds. As we keep adding biodiversity to the mix and begin valuing marginal plants as food rather than weeds, a new horticultural balance unfolds.

Native American gardens may be part of history, but the building blocks remain to bring this heritage into modern gardens in the form of flavorful, well-adapted varieties and growing techniques that reflect an understanding of each plant’s important role in the system as a whole.
Read more:

Discover rare vegetable varieties in Seed Varieties for Your Native American Garden (http://www.motherearthnews.com/organic-gardening/native-american-garden-zm0z13fmzsto.aspx), and learn about two seedsmen who did extensive work to preserve native corn varieties in Preserving Native American Seed Heritage (http://www.motherearthnews.com/organic-gardening/native-american-seed-zm0z13fmzsto.aspx).


What natural and anthropogenic processes influence biodiversity, ecosystem functioning, and ecosystem stability? How can ecology increase our ability to understand and manage ecosystems?

Biodiversity is the diversity of life on Earth. This includes the richness (number), evenness (equity of relative abundance), and composition (types) of species, alleles, functional groups, or ecosystems. Biodiversity is rapidly declining worldwide, and there is considerable evidence that ecosystem functioning (e.g., productivity, nutrient cycling) and ecosystem stability (i.e., temporal invariability of productivity) depend on biodiversity (Naeem et al. 2009). Thus, biodiversity declines may diminish human wellbeing by decreasing the services that ecosystems can provide for people (Millennium Ecosystem Assessment 2005).

Although the causes and consequences of contemporary biodiversity declines have been extensively explored in ecology, several questions deserve further consideration. For example, what natural processes influence biodiversity; what anthropogenic processes influence biodiversity; what are the consequences of biodiversity declines? Thus far, these questions have been considered separately within several ecological fields. Here, I briefly describe previous progress in each of these fields and then offer a conceptual and mechanistic synthesis across these fields. I conclude by suggesting novel questions and hypotheses that could be considered in future studies to increase our ability to understand, conserve, and restore ecosystems.

What Natural Processes Influence Biodiversity?

Theoretical and empirical studies have identified a vast number of natural processes that can potentially maintain biodiversity. Biodiversity can be maintained by moderately intense disturbances that reduce dominance by species that would otherwise competitively exclude subordinate species. For example, selective grazing by bison can promote plant diversity in grasslands (Collins et al. 1998). Additionally, biodiversity can be maintained by resource partitioning, when species use different resources, or spatiotemporal partitioning, when species use the same resources at different times and places. For instance, plant species in the tundra can coexist by using different sources of nitrogen or use the same sources of nitrogen at different times of the growing season or at different soil depths (McKane et al. 2002). Furthermore, biodiversity can be maintained by interspecific facilitation, which occurs when species positively influence one another by increasing the availability of limiting resources, or by decreasing the limiting effects of natural enemies or physical stresses. Although previous theoretical and empirical studies have identified numerous processes that can maintain biodiversity, ecologists and conservationists rarely know which of these mechanisms actually maintains biodiversity at any particular time and place. Thus,
further investigation is needed to identify the natural processes that actually maintain biodiversity in intact ecosystems.

**What Anthropogenic Processes Influence Biodiversity?**

Human actions have resulted in multiple changes on a global scale that often drive contemporary biodiversity declines. In particular, land use changes, exotic species invasions, nutrient enrichment, and climate change are often considered some of the most ubiquitous and influential global ecosystem changes (Vitousek et al. 1997, Chapin et al. 2000, Benayas et al. 2009, Butchart et al. 2010). Unfortunately, the mechanisms by which global ecosystem changes influence biodiversity and ecosystem processes, and the combined effects of multiple changes, are often unclear. This greatly reduces the ability to predict future changes in biodiversity and ecosystem processes. Therefore, further investigation is needed to predict the consequences of global ecosystem changes.

In some cases, human actions have promoted biodiversity. Conservation strategies, such as creating parks to protect biodiversity hotspots, have been effective but insufficient (Bruner et al. 2001). For example, although biodiversity is often greater inside than outside parks, species extinctions continue. Similarly, restoration strategies, such as reinstating fire as a natural disturbance, have been effective but insufficient. Specifically, biodiversity and ecosystem services are greater in restored than in degraded ecosystems but lower in restored than in intact remnant ecosystems (Benayas et al. 2009). Despite the positive effects of conservation and restoration efforts, biodiversity declines have not slowed (Butchart et al. 2010). Thus, further investigation is needed to determine new conservation and restoration strategies.

**What are the Consequences of Biodiversity Declines?**

There is considerable evidence that contemporary biodiversity declines will lead to subsequent declines in ecosystem functioning and ecosystem stability (Naeem et al. 2009). Biodiversity experiments have tested whether biodiversity declines will influence ecosystem functioning or stability by manipulating some component of biodiversity, such as the number of species, and measuring various types of ecosystem functioning or stability. These studies have been conducted in lab, grassland, forest, marine, and freshwater ecosystems. From these studies, it is clear that ecosystem functioning often depends on species richness, species composition, and functional group richness and can also depend on species evenness and genetic diversity. Furthermore, stability often depends on species richness and species composition. Thus, contemporary changes in biodiversity will likely lead to subsequent changes in ecosystem properties. Further investigation at larger spatiotemporal scales in managed ecosystems is needed to improve our understanding of the consequences of biodiversity declines.

**Synthesizing Biodiversity Research**

A synthesis across four ecological fields may increase our ability to understand, conserve, and restore ecosystems by providing a framework for considering the causes and consequences of biodiversity declines (Figure 1). First, maintenance of biodiversity research has focused on the effects of natural processes on biodiversity (Figure 2A). Second, biodiversity-stability research has focused on the effects of biodiversity on various measures of stability (Figure 2B). Third, biodiversity-ecosystem functioning research has focused on the effects of biodiversity on ecosystem functioning and how this relationship mediates the effects of global ecosystem changes on human wellbeing (Figure 2C). Fourth, global change ecology has focused on the effects of global ecosystem changes on biodiversity, ecosystem functioning, and stability (Figure 2D). Combining the relationships explored in
each of these four fields produces an inclusive framework (Figure 2E) and elucidates two novel questions: What natural processes promote biodiversity, ecosystem functioning, and stability; do global ecosystem changes influence ecosystems by altering these natural processes?

**What Natural Processes Promote Biodiversity, Ecosystem Functioning, and Stability?**

The natural processes that are predicted to locally promote biodiversity, ecosystem stability, and ecosystem functioning have commonly been considered separately, but are quite congruent (Loreau 2010). Theoretical and empirical studies have identified mechanisms that can promote biodiversity (Figure 3A), ecosystem stability (Figure 3B), and ecosystem functioning (Figure 3C). Interestingly, stabilizing species interactions, which cause a species to limit itself more than it limits other species, are predicted to promote biodiversity, ecosystem stability, and ecosystem functioning (Figure 3). Previous studies have found that stabilizing species interactions can promote biodiversity, ecosystem stability, and ecosystem functioning (Isbell et al. 2009). Stabilizing species interactions occur when interspecific interactions (i.e., between individuals from different species) are more favorable than intraspecific interactions (i.e., between individuals of the same species). This results in a rare species advantage, common species disadvantage, or both. Species interactions are stabilizing when interspecific resource competition is less than intraspecific resource competition (McKane et al. 2002), interspecific apparent competition is less than intraspecific apparent competition (Chesson & Kuang 2008), interspecific facilitation is greater than intraspecific facilitation (Cardinale et al. 2002), or some combination of these mechanisms. For example, when species consume different resources or consume the same resources at different times or places, resource competition will be stronger between two individuals from the same species than between two individuals from different species. Consequently, species have an advantage when rare because competition is relatively weak and a disadvantage when common because competition is relatively strong. This can maintain biodiversity because it prevents any particular species from competitively excluding all other species. This can promote ecosystem stability in diverse ecosystems because it results in species asynchrony, wherein decreases in the abundance of some species are compensated for by increases in the abundance of other species. This can promote ecosystem functioning in diverse ecosystems because it results in overyielding, in which species perform better when they are rare and other species are present than when they are common and other species are absent.

Future studies can be designed to determine the relative importance of various types of stabilizing species interactions (Figure 4). The relative importance of competition v. facilitation can be determined by manipulating the density of individuals. Competition is greater than facilitation when individuals perform better at low than high density. Adding resources and removing natural enemies can elucidate the relative importance of resources and natural enemies, respectively. Ecologists have often focused on resource competition, but recent studies suggest that facilitation (Brooker et al. 2008) and natural enemies (Chesson & Kuang 2008) have been under-appreciated in ecology. Thus, further study is needed to determine which types of stabilizing species interactions commonly promote biodiversity, ecosystem functioning, and ecosystem stability.

**Do Global Ecosystem Changes Influence Ecosystems by Altering these Natural Processes?**

It may be possible to predict future changes in biodiversity, ecosystem functioning, and ecosystem stability by considering how global ecosystem changes are currently influencing stabilizing species interactions. The United Nations is currently
developing an Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) to monitor biodiversity and ecosystem services worldwide (Marris 2010). The IPBES will be modeled after the Intergovernmental Panel on Climate Change (IPCC), and there is great potential for ecologists to borrow strategies that have been successfully employed by climatologists. For example, climatologists have modeled the effects of natural and anthropogenic processes on radiative forcing (i.e., the change in the difference between the amount of radiation entering and exiting Earth's atmosphere) to determine the causes and consequences of climate change (IPCC 2007). Radiative forcing is central to this discussion because it is influenced by both natural and anthropogenic processes and it influences many climate variables. Future ecological studies could take a similar approach to determine the causes and consequences of changes in biodiversity. Stabilizing species interactions are central to this discussion because they can be influenced by both natural and anthropogenic processes, and they can influence both biodiversity and ecosystem properties (Figure 1). I hypothesize that global ecosystem changes are currently destabilizing species interactions (Figure 5) and that this will lead to future declines in biodiversity, ecosystem functioning, and ecosystem stability. Collaborations among investigators considering one or more of the relationships in Figure 1 are becoming increasingly common (Naeem et al. 2009), and this will continue to be an active area of research.

References and Recommended Reading


(a) Maintenance of Biodiversity
- Stabilizing Mechanisms
- Equalizing Mechanisms

(b) Biodiversity—Ecosystem Stability
- Overyielding Effect
- Species Asynchrony

(c) Biodiversity—Ecosystem Functioning
- Complementarity Effect
- Selection Effect

Synthesis

Biodiversity
- Equalizing Mechanisms

(d) Species Interactions

Ecosystem Stability
- Stabilizing Effects

Ecosystem Functioning
- Selection Effect

© 2010 Nature Education Citation
Anthropogenic Processes
- Land-use changes
- Exotic species invasions
- Nutrient enrichment
- Climate change
- Conservation
- Restoration

Natural Processes
- Resource partitioning
- Natural enemy partitioning
- Resource facilitation
- Natural enemy facilitation

Net Effect
The planet is heating up faster than species can migrate

A new study finds evidence of many local extinctions

By MARLENE CIMONS NEXUS MEDIA  DECEMBER 9, 2016

Visitors to the Santa Catalina Mountains just outside Tucson, Arizona encounter a very disturbing sight: patches of dead alligator junipers scattered across hillsides at the base of the range. Wildfires did not destroy these trees—climate change did.

The trees can’t survive where it’s hot, so many have moved to higher elevations, where it is cooler. But if the heat keeps rising, they will die there too, and eventually cease to exist entirely.

“They can’t cope with the conditions,” says John J. Wiens, professor of ecology and evolutionary biology at the University of Arizona. “They simply can’t change fast enough.”

What is far worse, however, is that this is no isolated example.

The plight of the alligator juniper is but one obvious piece of a frightening pattern of local extinction currently underway “everywhere, all over the planet,” Wiens says, “It is happening among birds, plants, animals, in the ocean and in the freshwater environment.”

Climate change could doom numerous species irreversibly, including those that people depend on for resources and food. “If it’s happening a little now, it will happen a lot in the future,” Wiens says. “We have a moral imperative to be sure that the future does not play out.”

The trend is especially troubling in tropical and subtropical environments—lowland places like the rainforest, where climate-threatened species have nowhere else to go. “For plants and animals that can’t move, they’re dead,” Wiens says.

Wiens recently examined the fate of hundreds of plant and animal species around the world, concluding that local extinctions already have occurred in nearly half of the 976 species he studied. His research, published today in PLOS Biology, found that 450 plant and animal species have disappeared locally, a result he finds especially striking, since mean temperatures have increased less than 1 degree Celsius since the pre-industrial era.

“Local extinctions are already widespread,” he says. “The results suggest that even modest changes in climate are enough to drive local populations in many species to extinction. They also suggest that local populations in many species cannot shift their climatic niches rapidly enough to prevent extinction. We know the climate is going to change even more, which bodes really badly for overall survival.”

Camilo Mora, assistant professor of geography at the University of Hawaii at Mānoa, who has studied the impact of climate change on plant growth, describes Wiens’ work as an important new piece of evidence of “the massive destruction of nature” caused by human-induced warming.
“The fingerprint of climate change on nature is demonstrated yet again,” says Mora, who was not involved in Wiens’ study. “This is not rocket science. Whenever you heat up a place, species are forced to deal with it. Climate change, compounded by other stressors, appears to be too much for species to take. Clearly, we are making it hard for species to endure us.”

Jeremy Kerr, a professor of biology at the University of Ottawa who has studied the effects of climate change on bumblebees, called these growing extinctions “dangerous [because] we rely on a lot of these species for ecosystem services we can’t really do without, like pollination.”

“Some of the species that are disappearing serve critical functions,” he adds. “We all know about monarch butterflies, one of the most beautiful animals in the world. Climate change… is contributing to their decline. Other animals that are even more important for practical reasons are bumblebees, and we now know that climate change is part of the reason for their decline also. These losses chip away at the planet’s life support systems, which we need.”

David Inouye, a professor emeritus of biology at the University of Maryland who studies the impact of climate change on the environment, agrees.

“Scientists have predicted for a while now that we are entering the sixth major mass extinction event in the history of life on the planet,” he says. “Evidence for this is now accumulating…this study provides insights into the range shifts that can already be documented in both plants and animals in response to the changing climate, and how the dynamics of range shifts can lead to local, and eventually, global extinctions.”

In fact, Inouye says, he has seen similar trends in his own research. “In my work in the Rocky Mountains, we have observed several species of animals, from moose to mosquitoes, moving up in altitude, and plants disappearing from the lower part of their former ranges,” he says. “Bumblebees are also moving up in altitude. If plants and pollinators don’t move at the same rates, historic interactions will be disrupted, potentially leading to more examples of local extinctions.”

Even those species that try to move upward may not be able to do so, according to the new study. Human factors, such as agriculture, roads, and increasing urbanization may impede their ability to relocate by leaving them no other live-able habitats, the study says.

Moreover, “many species are already confined to islands, peninsulas and mountaintops where dispersal to higher latitudes or elevations may not be possible,” the study says, adding: “Even if dispersal is unimpeded by human or natural barriers, it may simply occur too slowly to allow species to remain within their climatic niche.”

If the heat doesn’t kill directly, it can encourage potentially dangerous interactions, Wiens says. Certain plants may become vulnerable to beetle attacks, for example, and amphibians are prone to the deadly chytrid fungus, whose growth is stimulated by heat.

“In Arizona, we no longer have any natural Tarahumara frog populations because of the fungus,” Wiens says. “Climate is the basic cause, but the proximate cause may be something else.”

For his study, Wiens conducted a meta-analysis of dozens of existing studies demonstrating how species have shifted their geographic ranges over time in response to global warming. Using these “range-shift” studies, he found that local extinctions have occurred in the warmest parts of the ranges for nearly half of the plant and animal species studied.

His research also found that local extinctions varied by region, and were more than twice as likely to occur among tropical species compared to those in more temperate locations. This latter is important because most plant and animal species live in the tropics.
“If species live in a preserve in the topics, or in a place that has been deforested, it’s not really possible for them to move,” Wiens says. “They may be able to move up a mountain in Arizona, but that’s not going to work in a rainforest.”

“We are locked into a climate pattern, and things don’t seem to be able to adapt,” added Wiens. “This is only going to get worse if the climate warms further.”

Mora, of the University of Hawaii, agrees. “When places start failing to meet basic human needs for water… We will also very likely start seeing people moving as well,” he says. “Our planet is increasingly becoming unsuitable for many species, potentially even us.”

Marlene Cimons writes for Nexus Media, a syndicated newswire covering climate, energy, policy, art and culture.
In 1997, the U.S. Fish and Wildlife Service declared the cactus ferruginous pygmy owl (Figure 1) a federally endangered species. Surveys found a dozen birds nesting in saguaro cacti in Pima County, Arizona. This discovery suddenly meant that the county had to do a better job planning its growth. The county’s Science Technical Advisory Team (STAT) conducted habitat surveys and recommended that the county develop a plan to protect the owl and a multitude of other species that depend on similar habitat and whose numbers were declining. The county heeded this advice and began to develop a Multispecies Conservation Plan (MSCP). This would allow the county to meet its obligations under the Endangered Species Act (ESA), yet continue to grow in an environmentally sustainable way.

With increasing awareness of the perils of unplanned growth, county citizens and officials wanted to protect other special aspects of the area. They were concerned about the loss of cultural identity and quality of life in the region. They eventually set forth an ambitious six-pronged plan called the Sonoran Desert Conservation Plan (SDCP). The MSCP, which protects critical habitat for priority vulnerable species, and corridors connecting these lands, is the main biological component of the SDCP. The SDCP also includes plans for the protection of mountain parks, restoration of riparian areas, historical and cultural preservation, ranch preservation, and a conservation reserve known as the Conservation Lands System (CLS). The CLS gives extra protection to hillsides and riparian areas for their habitat and scenic values and uses relative habitat value to determine how much land should be left in its natural state when a parcel is developed. The county updated its comprehensive land use plan to incorporate the CLS land protection guidelines. Together, the components of the SDCP represent a far-reaching and groundbreaking approach to smart growth and strategic conservation planning based on green infrastructure principles.

Figure 1: Cactus ferruginous pygmy owl.

Credit: Bob Miles, Arizona Fish and Game
Green Infrastructure — Linking Lands for Nature and People

**Highlights**

- The MSCP is one part of the SDCP, a larger land use and protection plan. In developing the SDCP, the county went above and beyond the requirements of the ESA to conserve biological corridors, habitat important to vulnerable species, and mountainous and riparian areas, as well as ranches and historic and cultural sites.

- The county updated its comprehensive land use plan to include the CLS and incorporated the CLS guidelines into the draft MSCP. The county Board of Supervisors has, for the most part, been holding developers to the CLS guidelines, even though they are just recommendations at this time.

- Citizen participation was critical to the development of the MSCP. A large public steering committee widely represented the various interests in the debate. In the process of deciding how the committee would operate, many of the members grew to trust each other. A subcommittee put forward recommendations for the content of the MSCP and persuaded the larger committee to endorse them. These recommendations weighed heavily in the plan the county produced for citizen review.

- The STAT stayed focused on the science of habitat protection and was not swayed by politics or the hot-button issues of the day. County administrators made it clear from the beginning that this was what they wanted, and they helped keep the STAT out of the limelight.

- The planning process led to the creation of a new national reserve—Ironwood Forest National Monument, managed by the Bureau of Land Management.

- The county and the Coalition for Sonoran Desert Protection, an alliance of conservation groups and neighborhood associations, have won more than a dozen local, regional, and national awards for their approaches to multiagency coordination, geographic information systems use, public education, community advocacy, and habitat modeling during the SDCP process.

**Background and Context**

The Tucson area has been one of the fastest growing regions of the country since World War II. Pima County currently loses an acre of desert every 2 hours to development. In 2000–2001, an average of almost 1,800 new residents moved to Pima County each month. By the end of the twentieth century, the region’s steady population growth had outpaced the county’s ability to establish and implement effective regional land-use and conservation planning, and the rapid development threatened many native plants and animals as well as the open space that makes the area special.

Pima County lies at the intersection of four ecological regions—the Sonoran and Chihuahuan deserts and the Rocky and Sierra Madre mountains—which makes the area home to a great diversity of wildlife and plants. The lush, undeveloped mountains also provide an important north-south migratory pathway for animals and birds.

**The Sonoran Desert Conservation Plan**

To protect these natural treasures Pima County has been working for more than 6 years on the Sonoran Desert Conservation Plan, a multifaceted plan to safeguard the area’s biological corridors and ecologically important wildlife habitat, riparian areas, ranches, and cultural and historical resources. The area covered by the SDCP includes 5.9 million acres, over which more than a dozen federal, state, and local governments and agencies have jurisdiction. The main component of the SDCP focused on protection of biological corridors and critical wildlife habitat is the Multispecies Conservation Plan (MSCP).

“Pima County is a really important model because it is a comprehensive, general land-use, habitat protection plan. It goes a long ways beyond the specific requirements [of the ESA].”

— Bruce Babbitt, former Secretary of the Interior
An Endangered Owl Gets the Ball Rolling

The impetus for developing the SDCP and the MSCP was the discovery in the late 1990s of the federally endangered cactus ferruginous pygmy owl in Pima County. The decline of the owl is caused by the growth of urban and agricultural areas, wood cutting, engineered changes in natural water flow patterns, and predation by house cats, which are now prevalent in the area due to rapid growth.

In response to finding the endangered owl in the county, officials enlisted a volunteer Science Technical Advisory Team (STAT), which advised the county that it would be wise to protect the habitat of a number of other rare species while they were protecting the owl's habitat. The area's rapid development threatens many animals and plants besides the owl. A broad habitat protection plan would help the county save money by keeping ahead of future endangered species issues.

The U.S. Fish and Wildlife Service (USFWS), which manages endangered species in the United States, requires jurisdictions where endangered species live to develop a habitat conservation plan (HCP) before new development is allowed in the endangered species' habitat. County administrators opted to take the STAT's advice and develop an MSCP (an HCP for more than one vulnerable species) to secure the future of the owl as well as 54 other "priority vulnerable species." These species include the Arizona shrew, southwestern willow flycatcher, desert box turtle, Tucson shovel-nosed snake, lowland leopard frog, and Sonora sucker, as well as other species of mammals, birds, reptiles, amphibians, fish, invertebrates, and plants. These organisms share the owl's preferred habitat—wooded riparian areas, desert scrub, plains, and desert grasslands—and their numbers are also declining.

One option for long-term management of endangered species allows the county to plan for economically and environmentally efficient growth and natural resource use through the process of applying for a "Section 10," or "incidental take," permit under the ESA. Development of an MSCP is part of this permit application process. A Section 10 permit allows a small number of the endangered species to be harmed, killed, or captured in the course of development and land use as long as habitat is protected in the most important areas. Without this permit, a “take,” or killing of an endangered species, is a federal crime. The MSCP helps minimize the effects on the listed species of development allowed under the Section 10 permit.

Work on MSCP Inspires Development of SDCP

The discovery that the owl was nesting in Pima County prompted the county to begin developing an MSCP. However, the county wanted not just to meet the requirements of the ESA, but also to comply with the spirit and intent of that law. The county wanted to address the problems that led to the owl’s listing in the first place and reverse the decline of a host of other vulnerable species. The community also recognized that its economic viability depended in part on protecting its natural assets and preserving its cultural identity.

The result is the Sonoran Desert Conservation Plan (SDCP), which extends protection to a range of species by conserving and restoring large-scale natural systems and addressing protection of other natural and cultural resources in the county that residents value. The initial elements of the plan were protection of critical habitat and biological corridors (from the MSCP), riparian areas, mountain parks, cultural resources, and ranches. As the SDCP evolved, historical preservation was added, as was a new conservation reserve system (the Conservation Lands System [see below]).

The strong interconnections of all these elements are critical to a viable land management plan that ensures continuing protection of biodiversity in Pima County. When fully implemented, the plan will help to define urban boundaries, slow sprawl, and protect the lands with the highest quality resources. Together, the planning components represent a far-reaching and groundbreaking approach to strategic conservation planning.
Development of the MSCP

The Draft Pima County Multi-species Conservation Plan lays out how the county proposes to meet the requirements of the ESA by focusing development on the least environmentally important lands, thereby protecting species habitat and increasing efficiency of urban growth by concentrating development. The goal of the MSCP is to “ensure the long-term survival of the full spectrum of plants and animals that are indigenous to Pima County through maintaining or improving the habitat conditions and ecosystem functions necessary for their survival” (Fromer, 2004)(Figure 2).

Area conservation groups were initially opposed to the development of an MSCP under Section 10 of the ESA because these plans have typically been geared toward developers and there has often been only one representative from the conservation community on MSCP committees in other areas. The Coalition for Sonoran Desert Protection organized specifically to serve as a voice for conservation in this process. The Coalition consists of about 40 conservation groups, including representatives of Defenders of Wildlife, Sierra Club, Tucson Audubon Society, and local neighborhood groups. The Coalition hired staff specifically to monitor and participate in the process. The Coalition and its director, Carolyn Campbell, have been integral to the whole SDCP planning effort.

Despite initial opposition, the county government set a goal of obtaining a Section 10 permit, which would allow continued development to expand the county’s tax base and let development projects move forward. Area developers saw the Section 10 permit as the surest way to minimize fines and regulatory delays to new building projects.

The conservation community insisted early on that sound science serve as the basis for the plan. They pointed to examples of other HCPs that hadn’t worked well because they did not have a sound scientific basis. County officials established the STAT, which over the course of about 4 years identified 54 priority vulnerable species besides the owl. The STAT worked with county personnel to use GIS modeling to identify important habitat for these organisms. The STAT consists entirely of people with biological expertise, including specialists in all the major species groups (plants, birds, reptiles, etc.). The county assembled the STAT with input from its chair, Dr. William Shaw, professor of wildlife and fisheries resources at the University of Arizona. The STAT includes representatives of most of the major land management agencies in the area. That they were all volunteers lent credibility to their work.

SDCP project director Maeveen Behan and Leslie Dierauf, then a USFWS biologist, created a “firewall” between the STAT and the politics of the process, which gave credibility to the science. The STAT did not have to consider political or economic impacts in their work. Their charge was to tell the
community what it would take to protect the owl and the other vulnerable species; the issue of obtaining the Section 10 permit was separate. The thinking was that if the STAT used sound science to delineate important habitat, the county would qualify for the permit. All the information on which decisions were based was available to the public and well documented.

The county’s focus on protecting a number of species allowed the STAT to take more of an ecosystem-oriented approach. Shaw said, “This was not the traditional approach for an HCP, which is very species-level. But biodiversity is more than a species-level phenomenon. We developed a land use plan to preserve the full spectrum of biodiversity in the county; the 55 species are surrogates for getting at the bigger picture of preserving biodiversity.” The STAT made land use recommendations based on the potential vulnerability of each species’ habitat to impacts from the county’s land use decisions. Shaw said they ended up with a robust model of critical habitat, which means that the map of important habitat doesn’t change much if you drop out individual species because many depend on the same habitats, such as riparian areas.

**MSCP Designates Critical Habitat through the Conservation Lands System**

The STAT prepared a map of interconnected habitat to be protected for the owl and other priority vulnerable species and designated land categories based on the importance of various land types as habitat for these species. Together, the map and the land category designations represent the Conservation Lands System (CLS). The CLS incorporates the information on critical habitat into the MSCP and SDCP. The three most biologically important categories of land in the CLS, in order, are

- important riparian areas,
- biological core areas (Figure 3, page 6), including the corridors connecting them, and
- multiple use areas.

The county used GIS to map the land categories so citizens could see and comment on the system. Based on USFWS mitigation plans in other places, the STAT produced guidelines on how land development could occur in each of the categories. For example, one guideline states that 80% of a parcel within the biological core area must be preserved in its natural state. This means that if a 10-acre lot falls entirely within the biological core zone, development can occur on only 2 acres. The CLS restrictions are on a per-parcel basis rather than regionwide to help protect private property rights. The CLS designations represent an important part of both the MSCP and the SDCP.

The CLS applies to about 2 million acres mainly in eastern Pima County, where the fastest growth has occurred. Reserves of various kinds already protect about half of the area covered by the CLS. The CLS grandfathered all current land use zoning, but the CLS applies now when a developer submits a request to change the zoning on an area or to increase the density above that for which it is already zoned. The county’s environmental planning manager works with developers affected by the CLS to help them determine exactly how the guidelines affect their projects. The CLS development percentages are currently only guidelines, but so far planning and zoning officials and the Board of Supervisors have been following them fairly strictly, with ongoing pressure from the Coalition. The county may have to codify the CLS guidelines or something similar to them into law to satisfy USFWS requirements for the Section 10 permit.

In 2001 the Arizona state legislature passed legislation called Growing Smarter, which required that all counties create or update their comprehensive land use plan. In a groundbreaking display of green infrastructure-based planning, Pima County adopted the CLS guidelines and map of critical habitat as the basis for its updated comprehensive land use plan. In this way, the MSCP, of which the CLS is a part, is already influencing how growth occurs in Pima County.

“The work on the biological corridors and critical habitat elements of the Sonoran Desert Conservation Plan revealed that biology is the basis for all other elements.”

— SDCP Pima County Web site
Figure 3: Biological core areas in Pima County and the corridors that connect them. This network of land represents the region’s important linked habitat.
Public Involvement

Public involvement has been critical to the development of the MSCP and SDCP. The centerpiece of the public participation process involved the work of the public steering committee. SDCP project director Behan is widely credited with encouraging the various stakeholder groups to come to the negotiating table. Nearly 90 people answered the county’s call for applications for the steering committee. The county accepted them all, making for an unwieldy group representing just about every land-based interest in the county. This group worked steadily for about 4 years; more than 50 active participants attended regularly, including representatives of developers, ranchers, realtors, neighborhood groups, conservation organizations, off-road enthusiasts, businesses, property rights groups, mining interests, and others. The county charged the steering committee with making recommendations to the Board of Supervisors about what the MSCP should entail, but provided little additional direction.

The first year of the steering committee’s meetings consisted of a series of educational lectures on topics such as the science of the cactus ferruginous pygmy owl, the contents of an HCP, and historic land use patterns in the county. The group hired a professional facilitator to guide the committee meetings, and spent a lot of time deciding on process issues, such as how they would vote and what constituted a consensus. They decided that recommendations would need a supermajority (two-thirds of a quorum) plus one vote to be accepted. People were reluctant to elect any leaders for the steering committee because they feared loss of control to other interests. The conservation community had a strong voice in the proceedings due to the ongoing involvement of Carolyn Campbell, the Coalition for Sonoran Desert Protection’s director (Figure 4). Representatives of the various interest groups stuck it out through this time-intensive process because they feared that if their positions weren’t clear and known, the county would develop its own recommendations, which might not address their concerns. Bill Arnold, a real estate agent in the county, told Time Magazine, “We believed it was better to be at one table rather than have a huge fight. Everyone was a winner in the end.”

“Most of the ranchers look at open space and protection of the habitat as positive.”
— Rancher Mac Donaldson, quoted in Seattle Post-Intelligencer, May 5, 2005

Figure 4: Carolyn Campbell, director of the Coalition, presents at a public meeting.

Photo courtesy of C. Campbell, Coalition for Sonoran Desert Protection
In 2004 the Coalition published a report called "Community Vision for the Sonoran Desert Conservation Plan." It outlines objectives that, in the Coalition’s view, must be part of the MSCP for it to be effective:

- specify conservation goals for each of the 55 priority vulnerable species based on its current status and threats,
- protect the most important lands,
- improve and consolidate current land use ordinances to ensure protection for the most important lands and most threatened species and habitats and to ease the permitting process for development,
- manage and monitor conserved land, and
- provide dedicated funding for implementation.

Eventually a subcommittee of about a dozen extraordinarily committed people, including Campbell, emerged and met repeatedly to hammer out some general recommendations, which they then convinced others on the committee to accept. The steering committee put forth a “Preferred Alternative” that described preferred details of the MSCP, including which methods should be used to protect land, which areas should be protected, and how the plan should be financed. The county accepted the steering committee’s recommendation report, but the MSCP is still a work in progress, and there is no guarantee that the recommendations will make it into the final plan.

The county has continued to work with this smaller citizens committee, the MSCP-Implementation Agreement (MSCP-IA) Drafting Committee, to reach consensus on some of the finer details of the plan, such as how offsite mitigation might occur. It’s currently uncertain whether the county will allow a developer to build on, say, 100% of a parcel within the biological core and instead purchase for conservation an area of the same relative habitat value elsewhere. If this is an option, the required rate of mitigation must be established (the number of acres preserved for every acre developed) and a process must be in place to determine how the mitigation lands will be laid out so that they form useful habitat for the priority vulnerable species. These issues are currently being deliberated by the MSCP-IA Drafting Committee.

All meetings of the public steering committee and STAT are open to the public and include public comment periods, and the county seeks comments on various aspects of the process and the project’s reports. The county estimates that there have been more than 400 public meetings since the process began. The county held open houses about once a month at various area libraries and meeting halls, at which scientists and county staff presented draft maps and were available to answer related questions. The county held additional public meetings in various regions during the processes of updating the comprehensive land use plan and deciding which lands to include in a 2004 open space bond, which was overwhelmingly approved by voters (see below for more information on this bond issue).

As part of the public education process, Pima County created Sonoran Desert Kids, which uses education, recreation, communication, and action to engage children in the issues and to educate them about the SDCP. The Sonoran Desert Kids Web site (http://www.co.pima.az.us/cmo/sdcp/kids) provides information, games, and activities (Figure 5) to engage children in conservation action.

Figure 5: A sample of children’s artwork created during an SDCP educational event.

Courtesy of Pima County
Current Status

The county released the first draft of the MSCP in January 2004 and the second draft in February 2005. The county has already begun implementing some of its recommendations by holding developers to the CLS guidelines, purchasing important habitat as funds allow, and assisting with the designation of a new national reserve—the Ironwood Forest National Monument. In spring 2005, consultants were working on the official documentation for submittal of the MSCP and associated documents to the USFWS. Under the STAT’s supervision, a consulting firm was developing an environmental impact statement and preparing a take permit analysis, which quantifies the incidental take (incidental harm or killing of the species allowed in the course of development as long as habitat is protected in the most important habitat areas) of owls and how to mitigate it, for submittal to the USFWS. The public will have additional opportunities to comment on these documents before they’re finalized by the end of 2005. The Pima County Board of Supervisors will eventually vote to approve submittal of the final MSCP, Section 10 permit application, and other associated documents to the USFWS for review. The USFWS estimates that it may be a year after submittal before they reach a decision on the permit. The Coalition looks forward to a pioneering agreement between the parties, and has said, “when this visionary model plan is completed, it will serve as a model for other communities embarking on systematic habitat conservation plans for protecting biologically important and sensitive areas” (CSDP, 2003b) throughout the West and the country.

Management/Stewardship

A plan for long-term management, monitoring, and stewardship of owl populations and publicly acquired lands is still being worked out by the STAT and its consultants. The MSCP must provide for monitoring of owl takes if the county is to receive its Section 10 permit.

Financing and Cost-Benefit Analysis

Financing for Planning

When the planning process got off the ground, Bruce Babbitt, of Arizona, was the U.S. Secretary of Interior. He was interested in the process of planning on such a large scale for the protection of so many different organisms, and was impressed by the community’s interest. He was instrumental in earmarking almost $1 million per year for 3 years to support the development of the science behind the plan. These monies came through Section 6 of the ESA for planning and paid mainly for the work of environmental consulting companies.

Financing for Implementation

Open Space Bonds

Pima County voters passed a 10-year bond dedicated partially to open space in May 2004. The county subsequently appointed a citizens’ committee to oversee the use of bond funds. The citizens’ advisory committee adopted a Nature Conservancy map depicting recommendations for priority land purchases to be funded by the bond ordinance. The total bond issue was $175 million; of that, at least $112 million will go toward habitat protection. This sum is about half of what the conservation community hoped for. Some of the remaining money is set aside specifically for protection of land important for cultural resources or flood control, but there may be some overlap of those

“If you create a better community in the end, doesn’t everybody win?”

— Developer Peter Backus, quoted in Audubon, May/June 2005
categories with important habitat. So far the county has acquired 20,000 acres for $45 million under the 2004 bond program. A previous open space bond in 1997 ($36.3 million total) had a similar allocation of funding.

Exploring Alternatives

Implementation is estimated to cost $40 million to $2 billion, depending which lands are protected. A commonly cited number is $500 million over 5 years. The highest land costs are northwest of the Tucson metropolitan area. However, the county needs to preserve important habitat land, not just the cheapest land. The open space bond can not fund land management and monitoring, and those costs are as yet unquantified.

The Coalition for Sonoran Desert Protection partnered with several other national, regional, and state conservation organizations to form the Financing Group, which researched the various open space and HCP funding mechanisms existing in the Southwest and made recommendations to the county. They found that communities that are most successful in attaining their conservation goals have (i) established multiple funding sources, and (ii) gained from strong partnerships between local government and concerned citizens.

The Financing Group recommended that the county

- issue a general obligation bond. (The county did this and voters approved it in 2004. A large part of the bond went for open space preservation and related concerns. [See above for more details.])
- impose a sales tax to take advantage of the area’s tourism business, which thrives on open space.
- pursue private foundation funding sources.
- dedicate a percentage of general funds and property taxes to open space protection.

The group also made the following recommendations for state-based funding, among others:

- adopt a state tax credit for people who donate conservation easements,
- allocate state general funds for open space purchases, operation, and preservation, and
- organize a state-sponsored pro-open space public relations campaign.

The economic analysis report completed for the county by a consultant lists state and federal grants, property taxes, sales taxes, and mitigation fees as options to consider as additional funding sources for plan implementation. The report makes the following recommendations, among others:

- build an endowment to stabilize the plan over the long-term,
- set up a mitigation land bank,
- build in regular revenue adjustments to account for inflation and increases in land values,
- be flexible with developers’ funding options, and
- develop a balance between taxes and fees so that the benefits and costs are shared by all beneficiaries.

The county has not yet proposed any other major funding source for implementing the plan besides the bond fund. County staff are pursuing Arizona Department of Transportation ISTEA (Intermodal Surface Transportation Efficiency Act Enhancements Program) money for scenic vistas acquisitions and matching grants under Section 6 of the ESA. With the Section 10 permit in hand, the county will be eligible for additional grant funding for land protection, but this will not fulfill the entire need.
Costs vs. Benefits

County officials hired a consultant to complete an economic impact analysis of potential costs and benefits of obtaining the Section 10 permit. The analysis showed that the county will realize important benefits by implementing a plan with strong conservation measures. Having the certainty of the permit will allow for a more straightforward and cost-efficient development process. The consultant predicts that this will lead to more development in a shorter period of time than if the county does not obtain the permit.

Without the Section 10 permit, the county would have to stop all development in areas where the owl occurs or require a separate MSCP for each new proposed development in the owl’s habitat area. County officials emphasize that the MSCP and the SDCP are not about stopping development but about fostering responsible growth while minimizing impacts to the landscapes that make the area special. Having a countywide strategy enables developers to plan further into the future because there is less uncertainty about which land uses will be permissible where. Failure to get approval for the MSCP and the Section 10 permit may result in continued, expensive lawsuits by developers and conservation organizations.

The Coalition notes an economic shift in the county away from removing resources from the land and toward increased demand for unspoiled natural places and experiences and the ecosystem benefits these places provide. Coalition staff note that many benefits of the SDCP are intangible and difficult to quantify and that opponents of the plan don’t count these intangibles when discussing the costs and benefits of the plan, so the costs may sometimes appear to outweigh the benefits. The Coalition argues that taking into account intangible benefits such as cleaner water, less traffic because of less sprawl, and the preservation of vistas puts the balance clearly in favor of implementing the plan. Research has established that scenic views and access to open space and the recreational opportunities it provides can be important factors when people decide where to live. These factors positively affect housing values, thereby generating more tax revenues.

Benefits

County officials realized the county would save money if they could redirect growth to areas close to existing infrastructure such as roads and sewer lines. They used this advantage to sell the community on the idea of applying for the Section 10 permit. Other benefits of the MSCP and the SDCP include:

- protect native species and their habitats
- protect ranch lands, which provide important habitat, a traditional way of life, and open space
- protect culturally and historically important sites
- provide recreational opportunities and preserve aesthetic beauty
- save money in the long run by protecting native species and their habitats before they’re at the brink of extinction
- slow urban sprawl, thereby reducing traffic congestion, commuting times, air pollution, and other costs associated with sprawl
- increase property values by preserving views, open space, clean water, recreational opportunities, and protecting against flood damage
- protect jobs by creating a more diverse economy and bringing more tourism dollars to the area
- improve efficiency of the economy by controlling wasteful uses of natural resources
- improve citizens’ health by encouraging walking and outdoor recreation and discouraging driving, thereby lessening pollution
- promote social unity among neighborhoods and communities as more people take advantage of outdoor recreational opportunities.

“The health of Arizona’s economy increasingly depends on having a healthy environment.”

— Coalition for Sonoran Desert Protection
Application of Green Infrastructure Principles

**Principle 1: Protect green infrastructure before development.**

The establishment of the CLS and its integration into the county land use plan demonstrates Pima County’s efforts to get out ahead of development, as does the county’s decision to protect habitat not just for the endangered cactus ferruginous pygmy owl but for 54 other priority vulnerable species (Figure 6) that share similar habitats. This strategy recognizes that it’s less expensive to protect species before they’re threatened or endangered.

**Principle 2: Engage a diverse group of stakeholders.**

The county allowed all citizens who were interested in sitting on the MSCP public steering committee to do so. The group included representatives of virtually all the interests in growth and development in the area. The large size of the group proved unwieldy at first, until the die-hard members of the group emerged. This smaller group still meets to develop recommendations on issues related to the MSCP and SDCP. Letting the group develop its own strategy for tackling the issues ensured representation of the various interests throughout the process. People with diverse interests gradually learned to trust each other and compromise.

The Coalition for Sonoran Desert Protection, which served as a voice for conservation in the SDCP process, represents a broad cross-section of local and national environmental groups who learned to collaborate to achieve a mutually agreeable goal. This sector’s voice was stronger because the groups spoke with one reasonable voice.

County administrators recruited experts from multiple government agencies and in various fields for the STAT. A citizen advisory committee oversees the open space bond issue and another is researching options for funding implementation of the SDCP. All meetings of the public steering committee and the STAT are open to the public and include public comment periods. In addition the county has held dozens of public meetings about various aspects of the SDCP and MSCP process.

**Principle 3: Linkage is key.**

Recognizing the great biodiversity in their area, the county chose to use the MSCP approach to protect habitat for the cactus ferruginous pygmy owl as well as for 54 other priority vulnerable species (Figure 7, page 13). Many of the species’ habitat requirements overlap. Because riparian areas provide some of the most important and rare habitat types, habitat protection can go hand-in-hand with flood control projects. Leaving riparian areas undeveloped is best for both habitat protection and flood damage control, which may allow bond issue funding to serve a dual purpose. The CLS aims to protect important linked habitat on a regionwide basis.

**Principle 4: Work at different scales and across boundaries.**

The SDCP is a countywide plan encompassing lands managed by various entities for different objectives. The SDCP set out from the beginning to accommodate various land use goals, from habitat protection and open space conservation to preserving ranches and historic and cultural resources. Through the CLS, the STAT identified the most important habitat areas and designated appropriate levels of development for the different categories of land.
**Principle 5: Use sound science.**

About 150 different experts commented on various aspects of the STAT’s work, and models were refined based on their input. Reed Noss, an early practitioner of landscape-scale conservation planning, and Laura Hood Watchman, director of habitat conservation planning for Defenders of Wildlife, reviewed the broader process to ensure that the methods used and the assumptions made were valid. County administrators staunchly protected the STAT from the political side of the issues, a fact that Noss and Watchman praised. The two reviewers also commended the county’s provision of the STAT with adequate financial resources and staff to get the job done. The reviewers described the SDCP as “a credible, science-based process designed to achieve clear and laudable goals for the long term conservation of biodiversity in Pima County” (Noss and Watchman, 2001). Noss said that the plan was in the “top 10% in scientific credibility of more than 300 habitat conservation plans that have won federal approval” (Davis, 2001).

**Principle 6: Fund up-front as a public investment.**

Since 1997 the voters of Pima County have approved two bonds, about $150 million of which are dedicated to open space protection. The county and various citizens’ groups are studying additional options for funding implementation of the SDCP in order to spread the financing responsibility among local, state, and national users of the area’s resources.

**Principle 7: Green infrastructure benefits all.**

Intense citizen participation provided a cornerstone of the MSCP and SDCP development processes and identified approaches acceptable to all parties. It is impossible to stop growth, so it’s preferable to develop a plan to ensure that it’s done in an environmentally responsible manner. Pima County government will save money by focusing growth in areas where roads, sewers, and electric lines already exist. Developers benefit from reduced regulatory review times, more clearly defined requirements, and less uncertainty about whether projects will be permitted. Citizens benefit through reduced commuting times, cleaner air and water, improved access to open space and its associated recreational opportunities, and flood control.

**Principle 8: Make green infrastructure the framework for conservation and development.**

Pima County’s SDCP embodies this principle. The habitat preservation needs of the region’s remaining undeveloped land now come before development needs. Incorporation of the CLS into the comprehensive land use plan gives the CLS greater regulatory strength. Through the SDCP, administrators have already identified the top priority parcels for conservation so they can move quickly to protect them when the parcels and/or funding become available.

---

“*The old debate about whether growth is good or bad is irrelevant. We have been growing for 50 years [in Tucson]. But we control where our growth occurs so it maximizes benefits and minimizes impacts.*”

— Chuck Huckelberry, Pima County administrator, quoted in Time Magazine, March 28, 2005
Evaluation

Unique, innovative, outstanding elements

- County administrators saw that the presence of the owl in the county presented them with an opportunity to encourage comprehensive land use planning. They understood that this type of planning could benefit the county in many ways.

- The integration of the CLS into the county land use plan and the large scale and multiple facets of the SDCP provide for a more comprehensive planning approach than most areas have undertaken. This should minimize conflicts between land use and conservation measures.

- Tremendous public participation and volunteer work enabled the effort to succeed. A subcommittee of the steering committee worked out the details of the committee’s recommendations to the county and convinced the others in their groups to support them. The result was increased trust among the various interests, rather than polarization, as so often happens with land use planning. Carolyn Campbell said, “This plan only sets a precedent if everyone’s holding hands and agreeing to this.”

- The county shielded the STAT from political pressures to favor one interest over another, and as a result, the STAT findings were based strictly on well documented science. Outside experts provided specialized knowledge and peer review. The STAT satisfied the concerns of most of the mainstream environmental and development groups.

Challenges

- The continuity of county leadership could become a problem because the SDCP process has been ongoing for several years. The sitting board of supervisors is supportive, but that could change as time passes.

- The 109th Congress may reauthorize the ESA and in the process weaken the act’s protections. It is unclear how reauthorization of the ESA ranks in comparison to the slate of other issues on the table. The act has been up for reauthorization for more than 12 years. The owl could be down-listed or de-listed, possibly because of healthy populations across the U.S. border in Mexico.

- Some areas of the county—the city of Tucson and the town of Marana—are working on their own Section 10 permit applications. It’s unclear how these will affect the county plan. Some developers were trying to have their land annexed into Marana so they would face less stringent building requirements. Both Tucson and Marana are using the county’s data and have many of the same experts working with them. The CLS does not cover the town of Marana. The town has recently annexed a lot of state land, and the county has requested that they apply the CLS requirements to those lands.

- The MSCP and SCDP are long-term plans based on the best currently available scientific data. But no amount of scientific knowledge can completely predict future events. This could mean that circumstances may change and the intended results may be unobtainable. For example, the “no surprises” clause of the ESA says that developers are not subject to further restrictions in the future even if the plan isn’t working to save owls. Developers favor the certainty this clause brings, but their certainty comes at the expense of the

"The SDCP has taken conservation planning to the next level by integrating ecosystems, economic growth, cultural resources, and development. This is an excellent model of creative planning that shows growing communities how to balance our built and natural environments."

— Bruce Knight, American Institute of Certified Planners
conservation community’s certainty that the species will be protected.

- Developing an effective and efficient resource management and associated monitoring plan remains a challenge.

- Finding the financial resources to implement the various parts of the SDCP, including the MSCP, is, as always, an issue. Some of the proposed funding mechanisms would require passage of state legislation. If the plan will serve as a model for other places facing ESA issues, the area might receive additional federal implementation funding. It is currently unclear how the management of protected lands will be funded.

- Implementation funding must be in place before the Section 10 permit is obtained, as mandated by the ESA.

- Combining concerns about the continuity of county leadership and financing for implementation, STAT chair Bill Shaw said, “It’s still a plan; it’s not real. How well it’s implemented is what’s important. I’m quite confident that if we really stick to the land use plan over the long-term we will actually conserve the species.” But the pressures of growth and politics will be great.

- The lack of detailed status and habitat information about some species makes it challenging to develop a plan that adequately protects them.

**Lessons Learned**

- It is essential early in the process to involve and educate all stakeholders on the issues covered by the plan, including elected and agency officials.

- The more public participation, the better. If people aren’t given their say from the beginning and allowed to feel ownership of the process and the outcome, they may be unhappy with the end result. The SDCP is a long-term plan, and the county needs widespread buy-in because community leadership will change.

- What happens between the beginning and the end of the permit planning process is very important. The conservation community wanted to see interim conservation measures enacted during the planning process, and they did—the CLS. This allowed the community to get used to changes gradually and built trust in county leaders.

- Elected officials should not just blindly follow the pattern set by other places facing ESA issues. Keeping the focus on planning and conserving biodiversity rather than on getting the permit brings a different perspective to the process and lends greater credibility to the science.

- Having a separate environmental advocacy group in addition to the STAT allowed the scientists to stay out of the politics. The Coalition was the environmental watchdog of both the Board of Supervisors and the STAT. Because the STAT members and the Coalition members had previously been colleagues in the conservation community, the Coalition members trusted them.

- It is essential to assemble a science committee with excellent credentials and respect in the conservation community.

- Everyone involved must document why each decision is made and be very open and honest about data and decisions and meetings.

- People must accept that there will never be enough data and that you have to put together a model that reflects the best expertise available.

What began as a plan for a specific species has become increasingly inclusive and comprehensive over time. The inclusiveness of the planning process has resulted in a groundswell of support for the SDCP. The SDCP and MSCP are not about whether Pima County continues to grow; it is about where the county will grow. By designing a plan for the urban environment that will work within a natural and cultural resource protection framework, Pima County is fostering an environmental ethic that will protect the community’s most valuable assets and contribute to a sustainable economy for many years to come.
References


Coalition for Sonoran Desert Protection. 2003b. The Sonoran Desert Conservation Plan. (all articles in the series)


ESI Corp Study Team. 2003. Pima County economic analysis Section 10 permit. Prepared for Pima County.


U.S. Fish and Wildlife Service. n.d. Consultation and Habitat Conservation Planning around the Nation.


For More Information:

Carolyn Campbell  
Director, Coalition for Sonoran Desert Protection  
300 East University Boulevard, #120  
Tucson, Arizona 85705  
ph. (520) 388-9925  
Carolyn@sonorandesert.org  
http://www.sonorandesert.org

Nicole Fyffe  
Pima County Administrator’s Office  
130 West Congress, 10th Floor  
Tucson, AZ 85701  
ph. (520) 740-8800  
Nicole.Fyffe@pima.gov  
http://www.pima.gov/sdcp/
About Green Infrastructure

Green infrastructure is a strategic approach to land and water conservation that links lands for the benefit of nature and people, helps identify conservation priorities, and provides a planning framework for conservation and development. Green infrastructure is different from conventional approaches to conservation because it looks at conservation values and actions in concert with land development and growth management. Green infrastructure projects bring public and private partners together to work collaboratively toward a common land conservation goal. They help move beyond jurisdictional and political boundaries by providing a process for identifying, protecting, and restoring interconnected green space networks that conserve natural ecosystem functions and provide associated benefits to human populations. The green infrastructure approach appeals to people concerned about biodiversity, habitat, and land conservation as well as people interested in open space and land use planning at the community, region, or statewide scale. It also appeals to smart growth advocates because of its potential to lessen impacts and reduce the costs of built infrastructure.

About the Authors/Designer

This green infrastructure case study was prepared by Mark Benedict, Joy Drohan, and Jo Gravely.

Mark Benedict is Senior Associate for Strategic Conservation and Training at The Conservation Fund. Dr. Benedict is a scientist with more than 25 years of experience in natural resource planning and management. He is considered a national expert on green infrastructure and greenways, and has written numerous documents and conducted many courses and workshops on these topics.

Joy Drohan is a freelance environmental science writer/editor. She is owner and manager of Eco-Write, LLC. She writes about environmental topics for federal land management agencies, colleges and universities, and nonprofit conservation organizations.

Jo Gravely is a freelance photographer/designer for nonprofits, writers, corporate clients, and others.

Green Infrastructure Case Study Series

This series of case studies highlights successful and innovative green infrastructure projects from around the country. The series was undertaken so that readers can learn from and improve upon approaches tried by others. We hope that thorough, well-documented examples will allow readers to see the many possibilities and to adapt successful practices to their unique situations and challenges. Each case study addresses the same basic pieces of the story: overview, highlights, background and context, process, public education and participation, results and products, management and stewardship, financing, application of green infrastructure principles, and evaluation. Eight principles of green infrastructure, which are elements of most successful efforts, form the core of the case studies. The series illustrates concrete, real-life examples of how to assess and protect green infrastructure, including details about how each step was implemented.

About The Conservation Fund

The Conservation Fund is a national, nonprofit land conservation organization that forges partnerships to protect America’s legacy of land and water resources. Through land acquisition, community planning, and leadership training, the Fund and its partners demonstrate sustainable conservation solutions emphasizing the integration of economic and environmental goals. Since 1985, the Fund has protected more than 4 million acres of open space, wildlife habitat, and historic sites across America.

The Conservation Fund’s Green Infrastructure Program was created in 1999 to build the capacity of land conservation professionals and their partners to undertake strategic conservation activities that are proactive, systematic, well integrated, and applied at multiple scales. The program is a cooperative effort of the Fund and multiple public and private partners. Program products include a national course, workshops and conference sessions, publications, case studies, demonstration projects, a Web site, and related educational materials.

The Conservation Fund would like to thank the Surdna Foundation and the USDA Forest Service for providing support for this and other Green Infrastructure Program products.
Congress passed the Endangered Species Preservation Act in 1966, providing a means for listing native animal species as endangered and giving them limited protection. The Departments of Interior, Agriculture, and Defense were to seek to protect listed species, and, insofar as consistent with their primary purposes, preserve the habitats of such species. The Act also authorized the U.S. Fish and Wildlife Service to acquire land as habitat for endangered species. In 1969, Congress amended the Act to provide additional protection to species in danger of “worldwide extinction” by prohibiting their importation and subsequent sale in the United States. This Act called for an international meeting to adopt a convention to conserve endangered species. One amendment to the Act changed its title to the Endangered Species Conservation Act.

A 1973 conference in Washington, D.C. led 80 nations to sign the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES), which monitors, and in some cases, restricts international commerce in plant and animal species believed to be harmed by trade.

Later that year, Congress passed the Endangered Species Act of 1973. It

- defined “endangered” and “threatened” [section 3];
- made plants and all invertebrates eligible for protection [section 3];
- applied broad “take” prohibitions to all endangered animal species and allowed the prohibitions to apply to threatened animal species by special regulation [section 9];
- required Federal agencies to use their authorities to conserve listed species and consult on “may affect” actions [section 7];
- prohibited Federal agencies from authorizing, funding, or carrying out any action that would jeopardize a listed species or destroy or modify its “critical habitat” [section 7];
- made matching funds available to States with cooperative agreements [section 6];
- provided funding authority for land acquisition for foreign species [section 8]; and
- implemented CITES protection in the United States [section 8].

Congress enacted significant amendments in 1978, 1982, and 1988, while keeping the overall framework of the 1973 Act essentially unchanged. The funding levels in the present Act were authorized through Fiscal Year 1992. Congress has annually appropriated funds since that time.

Principal amendments are listed below:

**1978:**

- Provisions were added to Section 7, allowing Federal agencies to undertake an action that would jeopardize listed species if the action is exempted by a Cabinet-level committee convened for this purpose;
- Critical habitat was required to be designated concurrently with listing a species, when prudent, and economic and other impacts of designation were required to be considered in deciding on boundaries [section 4];
- The Secretary of Agriculture (for the Forest Service) was directed to join the Secretaries of Interior, Commerce, and Defense in developing a program for conserving fish, wildlife and plants, including listed species; land acquisition authority was extended to all such species [section 5];
- The definition of “species” with respect to “populations” was restricted to vertebrates; otherwise, any species, subspecies, or variety of plant, or species or subspecies of animal remained eligible for protection under the Act [section 3].

**1982:**

- Determinations of the status of species were required to be made solely on the basis of biological and trade information, without consideration of possible economic or other effects [section 4];
to different treatment under section 4 for critical habitat, section 7 for interagency cooperation, and section 9 for prohibitions;

- Section 9 included a prohibition against removing endangered plants from land under Federal jurisdiction and reducing them to possession

- Section 10 introduced habitat conservation plans, providing “incidental take” permits for listed species in connection with otherwise lawful activities.

1988:

- Monitoring candidate and recovered species was required, with adoption of emergency listing when there is evidence of significant risk [section 4];

- Several amendments dealt with recovery matters: 1) recovery plans were required to undergo public notice and comment, and affected Federal agencies were required to give consideration to those comments; 2) new subsection 4(g) required five years of monitoring recovered species; and 3) biennial reports were required on the development and implementation of recovery plans and on the status of all species with plans;

- A new section 18 required a report of all reasonably identifiable expenditures by the Federal government and States that received section 6 funds on a species-by-species basis on the recovery of endangered or threatened species and

- Protection for endangered plants was extended to include a prohibition on malicious destruction on Federal land and other “take” that violates State law [section 9].

2004:


Section 4(a)(3) exempted the Department of Defense from critical habitat designations so long as an integrated natural resources management plan prepared under section 101 of the Sikes Act (16 U.S.C. 670a) and acceptable to the Secretary of the Interior is in place.

2009:


In a valuable training exercise, a 26-ton Marine Corps tank plows through pickleweed in wetland mudflats, improving habitat for endangered Hawaiian stilts before the nesting season.

Hawaiian stilt

Hawaiian stilt
Sustaining life on Earth

How the Convention on Biological Diversity promotes nature and human well-being

Secretariat of the Convention on Biological Diversity

UNEP
Table of contents

Foreword ........................................... i
Preface ............................................. ii
Biodiversity – the web of life .................... 2
We are changing life on earth .................... 3
The value of biodiversity
Biodiversity under threat
An agreement for action ......................... 7
A new philosophy
National action ................................. 9
Surveys
Conservation and sustainable use
Reporting
International action ........................... 13
Thematic programmes and “cross-cutting” issues.
Sharing the benefits of genetic resources
Traditional knowledge
Financial and technical support
The Biosafety Protocol
What are the next steps? ..................... 17
Promoting the long term
Information, education and training
What can I do about biodiversity?
Conclusion ..................................... 20
Preface

In a world of increasing globalization and environmental degradation, management of its most precious living resource, biological diversity, is one of the most important and critical challenges facing humankind today.

Biological diversity is the resource upon which families, communities, nations and future generations depend. It is the link between organisms, binding each into an interdependent community or ecosystem in which all living creatures have their place and role. It is the very web of life.

Despite its importance, our heedless actions are eroding this resource at a perilous rate. The world is impoverished, even threatened, by this loss. Every gene, species and ecosystem lost erodes the planet’s ability to cope with change. For the poorest, in the world this flexibility is a matter of life and death. For all of humankind it diminishes the quality of life.

A major cause of this erosion is that individuals, communities and nations take the resource for granted. There is an assumption, based on thousands of years of development, that living resources and biological diversity are limitless. Despite isolated instances of where communities, even civilizations, have ignored this responsibility and suffered dramatically as a result, for most of us the idea that we might be reaching the limits of its endurance is beyond our experience and comprehension. An important step to address our overuse of the biosphere lies in educating people. An education that empowers and enables people to seek collective ways to overcome current destructive trends is critical component of any successful strategy for achieving a sustainable future.

The Convention represents an important part of the effort to address this issue. Yet few people understand what is the term “biodiversity” actually means, let alone the goals and processes of the Convention. This Guide will make an important contribution addressing this barrier by explaining the somewhat arcane practices and terminology of this important endeavor in a simple and clear way. On a more personal note, as people and the public have been at the centre of my efforts to build a better future, I am especially pleased to have the chance to support this Guide.

Hamdallah Zedan
Executive Secretary
CBD

Klaus Töpfer
Executive Director
UNEP
Biodiversity – the web of life

Biological diversity – or biodiversity – is the term given to the variety of life on Earth and the natural patterns it forms. The biodiversity we see today is the fruit of billions of years of evolution, shaped by natural processes and, increasingly, by the influence of humans. It forms the web of life of which we are an integral part and upon which we so fully depend.

This diversity is often understood in terms of the wide variety of plants, animals and microorganisms. So far, about 1.75 million species have been identified, mostly small creatures such as insects. Scientists reckon that there are actually about 13 million species, though estimates range from 3 to 100 million.

Biodiversity also includes genetic differences within each species – for example, between varieties of crops and breeds of livestock. Chromosomes, genes, and DNA – the building blocks of life – determine the uniqueness of each individual and each species.

Yet another aspect of biodiversity is the variety of ecosystems such as those that occur in deserts, forests, wetlands, mountains, lakes, rivers, and agricultural landscapes. In each ecosystem, living creatures, including humans, form a community, interacting with one another and with the air, water, and soil around them.

It is the combination of life forms and their interactions with each other and with the rest of the environment that has made Earth a uniquely habitable place for humans. Biodiversity provides a large number of goods and services that sustain our lives.

At the 1992 Earth Summit in Rio de Janeiro, world leaders agreed on a comprehensive strategy for “sustainable development” – meeting our needs while ensuring that we leave a healthy and viable world for future generations. One of the key agreements adopted at Rio was the Convention on Biological Diversity. This pact, among the vast majority of the world’s governments sets out commitments for maintaining the world’s ecological underpinnings as we go about the business of economic development.

The Convention establishes three main goals: the conservation of biological diversity, the sustainable use of its components, and the fair and equitable sharing of the benefits from the use of genetic resources.

This booklet looks at the importance of biological diversity for the health of people and the planet. It explains the role of the Convention in protecting this biodiversity and ensuring that it is used for the benefit of all.

1 - We are changing life on Earth

The rich tapestry of life on our planet is the outcome of over 3.5 billion years of evolutionary history. It has been shaped by forces such as changes in the planet’s crust, ice ages, fire, and interaction among species.

Now, it is increasingly being altered by humans. From the dawn of agriculture, some 10,000 years ago, through the Industrial Revolution of the past three centuries, we have reshaped our landscapes on an ever-larger and lasting scale. We have moved from hacking down trees with stone tools to literally moving mountains to mine the Earth’s resources. Old ways of harvesting are being replaced by more intensive technologies, often without controls to prevent over-harvesting. For example, fisheries that have fed communities for centuries have been depleted in a few years by huge, sonar-guided ships using nets big enough to swallow a dozen jumbo jets at a time. By consuming ever more of nature’s resources, we have gained more abundant food and better shelter, sanitation, and health care, but these gains are often accompanied by increasing environmental degradation that may be followed by declines in local economies and the societies they supported.

In 1999, the world’s population hit 6 billion. United Nations experts predict the world will have to find resources for a population of 9 billion people in 50 years. Yet our demands on the world’s natural resources are growing even faster than our numbers; since 1950, the population has more than doubled, but the global economy has quintupled. And the benefits are not equally spread: most of the economic growth has occurred in a relatively few industrialized countries.

At the same time, our settlement patterns are changing our relationship with the environment. Nearly half the world’s people live in towns and cities. For many people, nature seems remote from their everyday lives. More and more people associate food with stores, rather than with their natural source.

The value of biodiversity

Protecting biodiversity is in our self-interest. Biological resources are the pillars upon which we build civilizations. Nature’s products support such diverse industries as agriculture, cosmetics, pharmaceuticals, pulp and paper, horticulture, construction and waste treatment. The loss of biodiversity threatens our food supplies, opportunities for recreation and tourism, and sources of wood, medicines and energy. It also interferes with essential ecological functions.

Our need for pieces of nature we once ignored is often important and unpredictable. Time after time we have rushed back to nature’s cupboard for cures to illnesses or for infusions of tough genes from wild plants to save our crops from pest outbreaks. What’s more, the vast
array of interactions among the various components of biodiversity makes the planet habitable for all species, including humans. Our personal health, and the health of our economy and human society, depends on the continuous supply of various ecological services that would be extremely costly or impossible to replace. These natural services are so varied as to be almost infinite. For example, it would be impractical to replace, to any large extent, services such as pest control performed by various creatures feeding on one another, or pollination performed by insects and birds going about their everyday business.

"Goods and Services" provided by ecosystems include:

- Provision of food, fuel and fibre
- Provision of shelter and building materials
- Purification of air and water
- Detoxification and decomposition of wastes
- Stabilization and moderation of the Earth’s climate
- Moderation of floods, droughts, temperature extremes and the forces of wind
- Generation and renewal of soil fertility, including nutrient cycling
- Pollination of plants, including many crops
- Control of pests and diseases
- Maintenance of genetic resources as key inputs to crop varieties and livestock breeds, medicines, and other products
- Cultural and aesthetic benefits
- Ability to adapt to change

Biodiversity under threat

When most people think of the dangers besetting the natural world, they think of the threat to other creatures. Declines in the numbers of such charismatic animals as pandas, tigers, elephants, whales, and various species of birds, have drawn world attention to the problem of species at risk. Species have been disappearing at 50-100 times the natural rate, and this is predicted to rise dramatically. Based on current trends, an estimated 34,000 plant and 5,200 animal species – including one in eight of the world’s bird species – face extinction.

For thousands of years we have been developing a vast array of domesticated plants and animals important for food. But this treasurehouse is shrinking as modern commercial agriculture focuses on relatively few crop varieties. And, about 30% of breeds of the main farm animal species are currently at high risk of extinction.

While the loss of individual species catches our attention, it is the fragmentation, degradation, and outright loss of forests, wetlands, coral reefs, and other ecosystems that poses the greatest threat to biological diversity. Forests are home to much of the known terrestrial biodiversity, but about 45 per cent of the Earth’s original forests are gone, cleared mostly during the past century. Despite some regrowth, the world’s total forests are still shrinking rapidly, particularly in the tropics. Up to 10 per cent of coral reefs – among the richest ecosystems – have been destroyed, and one third of the remainder face collapse over the next 10 to 20 years. Coastal mangroves, a vital nursery habitat for countless species, are also vulnerable, with half already gone.

Global atmospheric changes, such as ozone depletion and climate change, only add to the stress. A thinner ozone layer lets more ultraviolet-B radiation reach the Earth’s surface where it damages living tissue. Global warming is already changing habitats and the distribution of species. Scientists warn that even a one-degree increase in the average global temperature, if it comes rapidly, will push many species over the brink. Our food production systems could also be seriously disrupted. The loss of biodiversity often reduces the productivity of ecosystems, thereby shrinking nature’s basket of goods and services,
from which we constantly draw. It destabilizes ecosystems, and weakens their ability to deal with natural disasters such as floods, droughts, and hurricanes, and with human-caused stresses, such as pollution and climate change. A ready, we are spending huge sums in response to flood and storm damage exacerbated by deforestation; such damage is expected to increase due to global warming.

The reduction in biodiversity also hurts us in other ways. Our cultural identity is deeply rooted in our biological environment. Plants and animals are symbols of our world, preserved in flags, sculptures, and other images that define us and our societies. We draw inspiration just from looking at nature’s beauty and power.

While loss of species has always occurred as a natural phenomenon, the pace of extinction has accelerated dramatically as a result of human activity. Ecosystems are being fragmented or eliminated, and innumerable species are in decline or already extinct. We are creating the greatest extinction crisis since the natural disaster that wiped out the dinosaurs 65 million years ago. These extinctions are irreversible and, given our dependence on food crops, medicines and other biological resources, pose a threat to our own well-being. It is reckless if not downright dangerous to keep chipping away at our life support system. It is unethical to drive other forms of life to extinction, and thereby deprive present and future generations of options for their survival and development.

Can we save the world’s ecosystems, and with them the species we value and the other millions of species, some of which may produce the foods and medicines of tomorrow? The answer will lie in our ability to bring our demands into line with nature’s ability to produce what we need and to safely absorb what we throw away.

While concern for the environment is constant in history, heightened concern about environmental destruction and loss of species and ecosystems in the seventies led to concerted action.

In 1972, the United Nations Conference on the Human Environment (Stockholm) resolved to establish the United Nations Environment Programme (UNEP). Governments signed a number of regional and international agreements to tackle specific issues, such as protecting wetlands and regulating the international trade in endangered species. These agreements, along with controls on toxic chemicals and pollution, have helped to slow the tide of destruction but have not reversed it. For example, an international ban and restrictions on the taking and selling of certain animals and plants have helped to reduce over-harvesting and poaching.

In addition, many endangered species survive in zoos and botanical gardens, and key ecosystems are preserved through the adoption of protective measures. However, these are stopgap actions. The long-term viability of species and ecosystems depends on their being free to evolve in natural conditions. This means that humans have to learn how to use biological resources in a way that minimizes their depletion. The challenge is to find economic policies that motivate conservation and sustainable use by creating financial incentives for those who would otherwise over-use or damage the resource.

In 1987, the World Commission on Environment and Development (the Brundtland Commission) concluded that economic development must become less ecologically destructive. In its landmark report, Our Common Future, it said that: “Humanity has the ability to make development sustainable – to ensure that it meets needs of the present without compromising the ability of future generations to meet their own needs”. It also called for “a new era of environmentally sound economic development”.

2 – An agreement for action

The reduction in biodiversity also hurts us in other ways. Our cultural identity is deeply rooted in our biological environment. Plants and animals are symbols of our world, preserved in flags, sculptures, and other images that define us and our societies. We draw inspiration just from looking at nature’s beauty and power.

While loss of species has always occurred as a natural phenomenon, the pace of extinction has accelerated dramatically as a result of human activity. Ecosystems are being fragmented or eliminated, and innumerable species are in decline or already extinct. We are creating the greatest extinction crisis since the natural disaster that wiped out the dinosaurs 65 million years ago. These extinctions are irreversible and, given our dependence on food crops, medicines and other biological resources, pose a threat to our own well-being. It is reckless if not downright dangerous to keep chipping away at our life support system. It is unethical to drive other forms of life to extinction, and thereby deprive present and future generations of options for their survival and development.

Can we save the world’s ecosystems, and with them the species we value and the other millions of species, some of which may produce the foods and medicines of tomorrow? The answer will lie in our ability to bring our demands into line with nature’s ability to produce what we need and to safely absorb what we throw away.
8

A new philosophy

In 1992, the largest-ever meeting of world leaders took place at the United Nations Conference on Environment and Development in Rio de Janeiro, Brazil. An historic set of agreements was signed at the "Earth Summit", including two binding agreements, the Convention on Climate Change, which targets its industrial and other emissions of greenhouse gases such as carbon dioxide, and the Convention on Biological Diversity, the first global agreement on the conservation and sustainable use of biological diversity. The biodiversity treaty gained rapid and widespread acceptance. Over 150 governments signed the document at the Rio conference, and since then more than 175 countries have ratified the agreement.

The Convention has three main goals:
- The conservation of biodiversity,
- Sustainable use of the components of biodiversity, and
- Sharing the benefits arising from the commercial and other utilization of genetic resources in a fair and equitable way.

The Convention is comprehensive in its goals, and deals with an issue so vital to humanity's future, that it stands as a landmark in international law. It recognizes – for the first time – that the conservation of biological diversity is "a common concern of humankind" and is an integral part of the development process. The agreement covers all ecosystems, species, and genetic resources. It links traditional conservation efforts to the economic goal of using biological resources sustainably. It sets principles for the fair and equitable sharing of the benefits arising from the use of genetic resources, notably those destined for commercial use. It also covers the rapidly expanding field of biotechnology, addressing technology development and transfer, benefit-sharing and biosafety. Importantly, the Convention is legally binding: countries that join it are obliged to implement its provisions.

The Convention reminds decision-makers that natural resources are not infinite and sets out a new philosophy for the 21st century, that of sustainable use. While past conservation efforts were aimed at protecting particular species and habitats, the Convention recognizes that ecosystems, species and genes must be used for the benefit of humans. However, this should be done in a way and at a rate that does not lead to the long-term decline of biological diversity.

The Convention offers decision-makers guidance based on the precautionary principle that there is a threat of significant reduction or loss of biological diversity, lack of full scientific certainty should not be used as a reason for postponing measures to avoid or minimize such a threat.

The Convention acknowledges that substantial investments are required to conserve biological diversity. It argues, however, that conservation will bring us significant environmental, economic and social benefits in return.

Some of the many issues dealt with under the Convention include:
- Measures and incentives for the conservation and sustainable use of biological diversity.
- Establishment of protected areas.
- Access to and transfer of technology, including biotechnology.
- Technical and scientific cooperation.
- Impact assessment.
- Education and public awareness.
- Provision of financial resources.
- National reporting on efforts to implement treaty commitments.

3 - National action

The Convention on Biological Diversity, as an international treaty, identifies a common problem, sets overall goals and policies and general obligations, and organizes technical and financial cooperation. However, the responsibility for achieving its goals rests largely with the countries themselves.

Private companies, landowners, fishermen, and farmers take most of the actions that affect biodiversity. Governments need to provide the legal, economic, and institutional framework to guide the use of natural resources, and by protecting biodiversity where they have direct control over the land and water.

Under the Convention, governments undertake to conserve and sustainably use biodiversity. They are required to develop national biodiversity strategies and action plans, and to integrate these into broader national plans for environment and development. This is particularly important for such sectors as forestry, agriculture, fisheries, energy, transportation and urban planning. Other treaty commitments include:
- Identifying and monitoring the important components of biological diversity that need to be conserved and used sustainably.
- Establishing protected areas to conserve biological diversity, while promoting environmentally sound development around these areas.
- Rehabilitating and restoring degraded ecosystems and promoting the recovery of threatened species in collaboration with local residents.
- Respecting, preserving and maintaining traditional knowledge of the sustainable use of biological diversity with the involvement of indigenous peoples and local communities.
- Preventing the introduction of, controlling, and eradicating alien species that could threaten ecosystems, habitats or species.
- Controlling the risks posed by organisms modified by biotechnology.
- Promoting public participation, particularly when it comes to assessing the environmental impacts of development projects that threaten biological diversity.
- Educating people and raising awareness about the importance of biological diversity and the need to conserve it.
- Reporting on how each country is meeting its biodiversity goals.
Surveys

One of the first steps towards a successful national biodiversity strategy is to conduct surveys to find out what biodiversity exists, its value and importance, and what is endangered. On the basis of these survey results, governments can set measurable targets for conservation and sustainable use. National strategies and programmes need to be developed or adapted to meet these targets.

Conservation and sustainable use

The conservation of each country’s biological diversity can be achieved in various ways. “In-situ” conservation – the primary means of conservation – focuses on conserving genes, species, and ecosystems in their natural surroundings, for example by establishing protected areas, rehabilitating degraded ecosystems, and adopting legislation to protect threatened species. “Ex-situ” conservation uses, e.g., botanical gardens and gene banks to conserve species.

Promoting the sustainable use of biodiversity will be of growing importance for maintaining biodiversity in the years and decades to come. Under the Convention, the “ecosystem approach to the conservation and sustainable use of biodiversity” is being used as a framework for action, in which all the goods and services provided by the biodiversity in ecosystems are considered. The Convention is promoting activities to ensure that everyone benefits from such goods and services in an equitable way.

There are many examples of initiatives to integrate the objectives of conservation and sustainable use:

• In 1994, Uganda adopted a programme under which protected wildlife areas shared part of their tourism revenues with local people. This approach is now being used in several African countries.

• In recognition of the environmental services that forests provide to the nation, Costa Rica’s 1996 Forestry Law includes provisions to compensate private landowners and forest managers who maintain or increase the area of forest within their properties.

• In different parts of the world, farmers are raising crops within mixed ecosystems. In Mexico, they are growing “shade coffee,” putting coffee trees in a mixed tropical forest rather than in monoculture plantations that reduce biodiversity. These farmers rely entirely on natural predators common to an intact ecosystem rather than on chemical pesticides.

• In Tanzania, problems surrounding the sustainable use of Lake Manyara, a large freshwater lake, arose following increased usage in recent decades. The aim was to manage the wetlands, including monitoring the groundwater and the chemistry of the escarpment water sources.

• In Clayoquot Sound on the western coast of Vancouver Island, Canada, the establishment of adaptive management to implement the ecosystem approach at the local level is currently under development with the involvement of indigenous communities, with a view to promoting the sustainable use of biodiversity.

• In different parts of the world, farmers are raising crops within mixed ecosystems. In Mexico, they are growing “shade coffee,” putting coffee trees in a mixed tropical forest rather than in monoculture plantations that reduce biodiversity. These farmers rely entirely on natural predators common to an intact ecosystem rather than on chemical pesticides.

• Through weekly “farmer field schools,” rice farmers in several Asian countries have developed their understanding of the functioning of the tropical rice ecosystem – including the interactions between insect pests of rice, their natural enemies, fish farmed in the rice paddies, and the crop itself – to improve their crop management practices.

This way they have increased their crop yields, while at the same time almost eliminating pesticide use with positive benefits in terms of environmental and human health. About 2 million farmers have benefited from this approach.

• In 1994, Uganda adopted a programme under which protected wildlife areas shared part of their tourism revenues with local people. This approach is now being used in several African countries.

• In recognition of the environmental services that forests provide to the nation, Costa Rica’s 1996 Forestry Law includes provisions to compensate private landowners and forest managers who maintain or increase the area of forest within their properties.

• In different parts of the world, farmers are raising crops within mixed ecosystems. In Mexico, they are growing “shade coffee,” putting coffee trees in a mixed tropical forest rather than in monoculture plantations that reduce biodiversity. These farmers rely entirely on natural predators common to an intact ecosystem rather than on chemical pesticides.

• Through weekly “farmer field schools,” rice farmers in several Asian countries have developed their understanding of the functioning of the tropical rice ecosystem – including the interactions between insect pests of rice, their natural enemies, fish farmed in the rice paddies, and the crop itself – to improve their crop management practices.

This way they have increased their crop yields, while at the same time almost eliminating pesticide use with positive benefits in terms of environmental and human health. About 2 million farmers have benefited from this approach.

• In Tanzania, problems surrounding the sustainable use of Lake Manyara, a large freshwater lake, arose following increased usage in recent decades. The aim was to manage the wetlands, including monitoring the groundwater and the chemistry of the escarpment water sources.

• In Clayoquot Sound on the western coast of Vancouver Island, Canada, the establishment of adaptive management to implement the ecosystem approach at the local level is currently under development with the involvement of indigenous communities, with a view to promoting the sustainable use of biodiversity.

There are many examples of initiatives to integrate the objectives of conservation and sustainable use:

• In 1994, Uganda adopted a programme under which protected wildlife areas shared part of their tourism revenues with local people. This approach is now being used in several African countries.

• In recognition of the environmental services that forests provide to the nation, Costa Rica’s 1996 Forestry Law includes provisions to compensate private landowners and forest managers who maintain or increase the area of forest within their properties.

• In different parts of the world, farmers are raising crops within mixed ecosystems. In Mexico, they are growing “shade coffee,” putting coffee trees in a mixed tropical forest rather than in monoculture plantations that reduce biodiversity. These farmers rely entirely on natural predators common to an intact ecosystem rather than on chemical pesticides.

• Through weekly “farmer field schools,” rice farmers in several Asian countries have developed their understanding of the functioning of the tropical rice ecosystem – including the interactions between insect pests of rice, their natural enemies, fish farmed in the rice paddies, and the crop itself – to improve their crop management practices.

This way they have increased their crop yields, while at the same time almost eliminating pesticide use with positive benefits in terms of environmental and human health. About 2 million farmers have benefited from this approach.

• In Tanzania, problems surrounding the sustainable use of Lake Manyara, a large freshwater lake, arose following increased usage in recent decades. The aim was to manage the wetlands, including monitoring the groundwater and the chemistry of the escarpment water sources.

• In Clayoquot Sound on the western coast of Vancouver Island, Canada, the establishment of adaptive management to implement the ecosystem approach at the local level is currently under development with the involvement of indigenous communities, with a view to promoting the sustainable use of biodiversity.

There are many examples of initiatives to integrate the objectives of conservation and sustainable use:

• In 1994, Uganda adopted a programme under which protected wildlife areas shared part of their tourism revenues with local people. This approach is now being used in several African countries.

• In recognition of the environmental services that forests provide to the nation, Costa Rica’s 1996 Forestry Law includes provisions to compensate private landowners and forest managers who maintain or increase the area of forest within their properties.

• In different parts of the world, farmers are raising crops within mixed ecosystems. In Mexico, they are growing “shade coffee,” putting coffee trees in a mixed tropical forest rather than in monoculture plantations that reduce biodiversity. These farmers rely entirely on natural predators common to an intact ecosystem rather than on chemical pesticides.

• Through weekly “farmer field schools,” rice farmers in several Asian countries have developed their understanding of the functioning of the tropical rice ecosystem – including the interactions between insect pests of rice, their natural enemies, fish farmed in the rice paddies, and the crop itself – to improve their crop management practices.

This way they have increased their crop yields, while at the same time almost eliminating pesticide use with positive benefits in terms of environmental and human health. About 2 million farmers have benefited from this approach.

• In Tanzania, problems surrounding the sustainable use of Lake Manyara, a large freshwater lake, arose following increased usage in recent decades. The aim was to manage the wetlands, including monitoring the groundwater and the chemistry of the escarpment water sources.

• In Clayoquot Sound on the western coast of Vancouver Island, Canada, the establishment of adaptive management to implement the ecosystem approach at the local level is currently under development with the involvement of indigenous communities, with a view to promoting the sustainable use of biodiversity.

There are many examples of initiatives to integrate the objectives of conservation and sustainable use:

• In 1994, Uganda adopted a programme under which protected wildlife areas shared part of their tourism revenues with local people. This approach is now being used in several African countries.

• In recognition of the environmental services that forests provide to the nation, Costa Rica’s 1996 Forestry Law includes provisions to compensate private landowners and forest managers who maintain or increase the area of forest within their properties.

• In different parts of the world, farmers are raising crops within mixed ecosystems. In Mexico, they are growing “shade coffee,” putting coffee trees in a mixed tropical forest rather than in monoculture plantations that reduce biodiversity. These farmers rely entirely on natural predators common to an intact ecosystem rather than on chemical pesticides.

• Through weekly “farmer field schools,” rice farmers in several Asian countries have developed their understanding of the functioning of the tropical rice ecosystem – including the interactions between insect pests of rice, their natural enemies, fish farmed in the rice paddies, and the crop itself – to improve their crop management practices.

This way they have increased their crop yields, while at the same time almost eliminating pesticide use with positive benefits in terms of environmental and human health. About 2 million farmers have benefited from this approach.

• In Tanzania, problems surrounding the sustainable use of Lake Manyara, a large freshwater lake, arose following increased usage in recent decades. The aim was to manage the wetlands, including monitoring the groundwater and the chemistry of the escarpment water sources.

• In Clayoquot Sound on the western coast of Vancouver Island, Canada, the establishment of adaptive management to implement the ecosystem approach at the local level is currently under development with the involvement of indigenous communities, with a view to promoting the sustainable use of biodiversity.

There are many examples of initiatives to integrate the objectives of conservation and sustainable use:

• In 1994, Uganda adopted a programme under which protected wildlife areas shared part of their tourism revenues with local people. This approach is now being used in several African countries.

• In recognition of the environmental services that forests provide to the nation, Costa Rica’s 1996 Forestry Law includes provisions to compensate private landowners and forest managers who maintain or increase the area of forest within their properties.

• In different parts of the world, farmers are raising crops within mixed ecosystems. In Mexico, they are growing “shade coffee,” putting coffee trees in a mixed tropical forest rather than in monoculture plantations that reduce biodiversity. These farmers rely entirely on natural predators common to an intact ecosystem rather than on chemical pesticides.

• Through weekly “farmer field schools,” rice farmers in several Asian countries have developed their understanding of the functioning of the tropical rice ecosystem – including the interactions between insect pests of rice, their natural enemies, fish farmed in the rice paddies, and the crop itself – to improve their crop management practices.

This way they have increased their crop yields, while at the same time almost eliminating pesticide use with positive benefits in terms of environmental and human health. About 2 million farmers have benefited from this approach.

• In Tanzania, problems surrounding the sustainable use of Lake Manyara, a large freshwater lake, arose following increased usage in recent decades. The aim was to manage the wetlands, including monitoring the groundwater and the chemistry of the escarpment water sources.
ensuring rational use of the forest and marine resources.

- Sian Ka'an Biosphere Reserve in Mexico has great cultural value with its 23 recorded Mayan and other archaeological sites while also being the home of some 800 people, mainly of Mayan descent. The reserve forms part of the extensive barrier reef system along the eastern coastline of Central America and includes coastal dunes, mangroves, marshes, and inundated and upland forests. The inclusion of local people in its management helps maintain the balance between pure conservation and the need for sustainable use of resources by the local community.

**Reporting**

Each government that joins the Convention is to report on what it has done to implement the accord and how effective this is in meeting the objectives of the Convention. These reports are submitted to the Conference of the Parties (COP) – the governing body that brings together all countries that have ratified the Convention. The reports can be viewed by the citizens of all nations. The Convention secretariat works with national governments to help strengthen reporting and to make the reports of various countries more consistent and comparable, so that the world community can get a clearer picture of the big trends. Part of that work involves developing indicators for measuring trends in biodiversity, particularly the effects of human actions and decisions on the conservation and sustainable use of biodiversity. The national reports, particularly when seen together, are one of the key tools for tracking progress in meeting the Convention’s objectives.

The Convention’s success depends on the combined efforts of the world’s nations. The responsibility to implement the Convention lies with the individual countries and, to a large extent, compliance will depend on informed self-interest and peer pressure from other countries and from public opinion. The Convention has created a global forum – actually a series of meetings – where governments, non-governmental organizations, academics, the private sector, and other interested groups or individuals share ideas and compare strategies.

The Conference of the Parties can rely on expertise and support from several other bodies that are established by the Convention:

- The Subsidiary Body on Scientific, Technical and Technological Advice (SBSTTA). The SBSTTA is a committee composed of experts from member governments competent in relevant fields. It plays a key role in making recommendations to the COP on scientific and technical issues.
- The Clearing House Mechanism. This Internet-based network promotes technical and scientific cooperation and the exchange of information.
- The Secretariat. Based in Montreal, it is linked to the United Nations Environment Programme. Its main functions are to organize meetings, draft documents, assist member governments in the implementation of the programme of work, coordinate with other international organizations, and collect and disseminate information.

In addition, the COP establishes ad hoc committees or mechanisms as it sees fit. For example, it created a Working Group on Biosafety that met from 1996 to 1999 and a Working Group on the knowledge of indigenous and local communities.
Thematic programmes and "cross-cutting" issues

The Convention's members regularly share ideas on best practices and policies for the conservation and sustainable use of biodiversity with an ecosystem approach. They look at how to deal with biodiversity concerns during development planning, how to promote transboundary cooperation, and how to involve indigenous peoples and local communities in ecosystem management. The Conference of the Parties has launched a number of thematic programmes covering the biodiversity of inland waters, forests, marine and coastal areas, drylands, and agricultural lands. Cross-cutting issues are also addressed on matters such as the control of alien invasive species, strengthening the capacity of member countries in taxonomy, and the development of indicators of biodiversity loss.

Sharing the benefits of genetic resources

A major part of the biodiversity debate involves access to and sharing of the benefits arising out of the commercial and other utilization of genetic material, such as pharmaceutical products. Most of the world's biodiversity is found in developing countries, which consider it a resource for fueling their economic and social development. Historically, plant genetic resources were collected for commercial use outside their region of origin or as inputs in plant breeding. Foreign bioprospectors have searched for natural substances to develop new commercial products, such as drugs. Often the products would be sold and protected by patents or other intellectual property rights, without fair benefits to the source countries.

The treaty recognizes national sovereignty over all genetic resources, and provides that access to valuable biological resources be carried out on "mutually agreed terms" and subject to the "prior informed consent" of the country of origin. When a microorganism, plant, or animal is used for a commercial application, the country from which it came has the right to benefit. Such benefits can include cash, samples of what is collected, the participation or training of national researchers, the transfer of biotechnology equipment, and know-how, and shares of any profits from the use of the resources.

Work has begun to translate this concept into reality and there are already examples of benefit-sharing arrangements. At least a dozen countries have established controls over access to their genetic resources, and an equal number of nations are developing such controls. Among the examples:

- In 1995, the Philippines required bioprospectors to get "prior informed consent" from both the government and local peoples.
- Costa Rica's National Institute of Biodiversity (INBIO) signed a historic bioprospecting agreement with a major drug company to receive funds and share in benefits from biological materials that are commercialized.
- Countries of the Andean Pact (Colombia, Ecuador, Peru, Bolivia and Venezuela) have adopted laws and measures to regulate access to their genetic resources. The bioprospector is required to meet certain conditions, such as the submission of duplicate samples of genetic resources collected to a designated institution; including a national institution in the collection of genetic resources; sharing existing information; sharing research results with the competent national authority; assisting in the strengthening of institutional capacities; and sharing specific financial or related benefits.

Through the Convention, countries meet to develop common policies on these matters.

Traditional knowledge

The Convention also recognizes the close and traditional dependence of indigenous and local communities on biological resources and the need to ensure that these communities share in the benefits arising from the use of their traditional knowledge and practices relating to the conservation and sustainable use of biodiversity. Member governments have undertaken "to respect, preserve and maintain" such knowledge and practices, to promote their wider application with the approval and involvement of the communities concerned, and to encourage the equitable sharing of the benefits derived from their utilization.

Financial and technical support

When the Convention was adopted, developing countries emphasized that their ability to take national actions to achieve global biodiversity benefits would depend on financial and technical assistance. Thus, bilateral and multilateral support for capacity building for investing in projects and programmes is essential for enabling developing countries to meet the Convention's objectives.

Convention-related activities by developing countries are eligible for support from the financial mechanism of the Convention: the Global Environment Facility (GEF). GEF projects, supported by the United Nations Environment Programme (UNEP), the United Nations Development Programme (UNDP) and the World Bank, help forge international cooperation and finance actions to address four critical threats to the global environment: biodiversity loss, climate change, depletion of the ozone layer, and degradation of international waters. By the end of 1999, the GEF had contributed nearly $1 billion for biodiversity projects in more than 120 countries.
The Biosafety Protocol

Since the domestication of the first crops and farm animals, we have altered their genetic makeup through selective breeding and cross-fertilization. The results have been greater agricultural productivity and improved human nutrition.

In recent years, advances in biotechnology techniques have enabled us to cross the species barrier by transferring genes from one species to another. We now have transgenic plants, such as tomatoes and strawberries that have been modified using a gene from a cold water fish to protect the plants from frost. Some varieties of potato and corn have received genes from a bacterium that enables them to produce their own insecticide, thus reducing the need to spray chemical insecticides. Other plants have been modified to tolerate herbicides sprayed to kill weeds. Living Modified Organisms (LMOs) – often known as genetically modified organisms (GMOs) – are becoming part of an increasing number of products, including foods and food additives, beverages, drugs, adhesives, and fuels. Agricultural and pharmaceutical LMOs have rapidly become a multi-billion-dollar global industry.

Biotechnology is being promoted as a better way to grow crops and produce medicines, but it has raised concerns about potential side effects on human health and the environment, including risks to biological diversity. In some countries, genetically altered agricultural products have been sold without much debate, while in others, there have been vocal protests against their use, particularly when they are sold without being identified as genetically modified.

In response to these concerns, governments negotiated a subsidiary agreement to the Convention to address the potential risks posed by cross-border trade and accidental releases of LMOs. A decade in January 2000, the Cartagena Protocol on Biosafety allows governments to signal whether or not they are willing to accept imports of agricultural commodities that include LMOs by communicating their decision to the world community via a Biosafety Clearing House, a mechanism set up to facilitate the exchange of information on and experience with LMOs. In addition, commodities that may contain LMOs are to be clearly labeled as such when being exported.

Stricter Advanced Informed Agreement procedures will apply to seeds, live fish, and other LMOs that are to be intentionally introduced into the environment. In these cases, the exporter must provide detailed information to each importing country in advance of the first shipment, and the importer must then authorize the shipment. The aim is to ensure that recipient countries have both the opportunity and the capacity to assess risks involving the products of modern biotechnology. The Protocol will enter into force after it has been ratified by 50 governments.

Economic development is essential to meeting human needs and to eliminating the poverty that affects so many people around the world. The sustainable use of nature is essential for the long-term success of development strategies. A major challenge for the 21st century will be making the conservation and sustainable use of biodiversity a compelling basis for development policies, business decisions, and consumer desires.

Promoting the Long Term

The Convention has already accomplished a great deal on the road to sustainable development by transforming the international community’s approach to biodiversity. This progress has been driven by the Convention’s inherent strengths of near universal membership, a comprehensive and science-driven mandate, international financial support for national projects, world-class scientific and technological advice, and the political involvement of governments. It has brought together, for the first time, people with very different interests. It offers hope for the future by forging a new deal between governments, economic interests, environmentalists, indigenous peoples and local communities, and the concerned citizen.

However, many challenges still lie ahead. After a surge of interest in the wake of the Rio Summit, many observers are disappointed by the slow progress towards sustainable development during the 1990s. Attention to environmental problems was distracted by a series of economic crises, budget deficits, and local and regional conflicts. Despite the promise of Rio, economic growth without adequate environmental safeguards is still the rule rather than the exception.

Some of the major challenges to implementing the Convention on Biological Diversity and promoting sustainable development are:

- Meeting the increasing demand for biological resources caused by population growth and increased consumption, while considering the long-term consequences of our actions.
- Increasing our capacity to document and understand biodiversity, its value, and threats to it.
- Building adequate expertise and experience in biodiversity planning.
- Improving policies, legislation, guidelines, and fiscal measures for regulating the use of biodiversity.
- Adopting incentives to promote more sustainable forms of biodiversity use.
- Promoting trade rules and practices that foster sustainable use of biodiversity.
- Strengthening coordination within governments, and between governments and stakeholders.
- Securing adequate financial resources for conservation and sustainable use, from both national and international sources.
- Making better use of technology.
- Building political support for the changes necessary to ensure biodiversity conservation and sustainable use.
- Improving education and public awareness about the value of biodiversity.
The Convention on Biological Diversity and its underlying concepts can be difficult to communicate to politicians and to the general public. Nearly a decade after the Convention first acknowledged the lack of information and knowledge regarding biological diversity, it remains an issue that few people understand. There is little public discussion of how to make sustainable use of biodiversity part of economic development.

The greatest crunch in sustainable development decisions is the short- versus the long-term time frame. Sadly, it often still pays to exploit the environment now by harvesting as much as possible as fast as possible because economic rules do little to protect long-term interests.

Truly sustainable development requires countries to redefine their policies on land use, food, water, energy, employment, development, conservation, economics, and trade. Biodiversity protection and sustainable use requires the participation of ministries responsible for such areas as agriculture, forestry, fisheries, energy, tourism, trade, and finance.

The challenge facing governments, businesses, and citizens is to forge transition strategies leading to long-term sustainable development. It means negotiating trade-offs even as people are clamoring for more land and businesses are pressuring for concessions to expand their harvests. The longer we wait, the fewer options we will have.

Information, education, and training

The transition to sustainable development requires a shift in public attitudes as to what is an acceptable use of nature. This can only happen if people have the right information, skills, and organizations for understanding and dealing with biodiversity issues. Governments and the business community need to invest in staff and training, and they need to support organizations, including scientific bodies, that can deal with and advise on biodiversity issues.

We also need a long-term process of public education to bring about changes in behaviour and lifestyles, and to prepare societies for the changes needed for sustainability. Better biodiversity education would meet one of the goals set out in the Convention.

What can I do about biodiversity?

While governments should play a leadership role, other sectors of society need to be actively involved. After all, it is the choices and actions of billions of individuals that will determine whether or not biodiversity is conserved and used sustainably.

In an era when economics is a dominant force in world affairs, it is more important than ever to have businesses willingly involved in environmental protection and the sustainable use of nature. Some companies have revenues far greater than those of entire countries, and their influence is immense. Fortunately, a growing number of companies have decided to apply the principles of sustainable development to their operations. For example, a number of forestry companies—often under intense pressure from environmental boycotts—have moved from clear-cutting to less destructive forms of timber harvesting. More and more companies have also found ways to make a profit while reducing their environmental impacts. They view sustainable development as ensuring long-term profitability and increased goodwill from their business partners, employees, and consumers.

Local communities play a key role since they are the true “managers” of the ecosystems in which they live and, thus, have a major impact on them. Many projects have been successfully developed in recent years involving the participation of local communities in the sustainable management of biodiversity, often with the valuable assistance of NGOs and intergovernmental organizations.

Finally, the ultimate decision-maker for biodiversity is the individual citizen. The small choices that individuals make add up to a large impact because it is personal consumption that drives development, which in turn uses and pollutes nature. By carefully choosing the products they buy and the government policies that they support, the general public can begin to steer the world towards sustainable development. Governments, companies, and others have a responsibility to lead and inform the public, but finally it is individual choices, made billions of times a day, that count the most.
Conclusion

Although still in its infancy, the Convention on Biological Diversity is already making itself felt. The philosophy of sustainable development, the ecosystem approach, and the emphasis on building partnerships are all helping to shape global action on biodiversity. The data and reports that governments are gathering and sharing with each other are providing a sound basis for understanding the challenges and collaborating on the solutions.

Much, much more needs to be done. The passage of the Earth’s biodiversity through the coming century will be its most severe test. With human population expected to rise dramatically, particularly in developing countries, and the consumer revolution set for exponential expansion – not to mention the worsening stresses of climate change, ozone depletion, and hazardous chemicals – species and ecosystems will face ever more serious threats. Unless we take action now, children born today will live in an impoverished world.

The Convention offers a comprehensive, global strategy for preventing such a tragedy. A richer future is possible. If governments and all sectors of society apply the concepts embodied in the Convention and make the conservation and sustainable use of biological diversity a real priority, we can ensure a new and sustainable relationship between humanity and the natural world for the generations to come.

For more information about the Convention, please contact:

Secretariat of the Convention on Biological Diversity
World Trade Centre
393 St Jacques ouest, Suite 300
Montreal, Quebec Canada H2Y 1N9
Phone: +1 (514) 288 2220
Fax: +1 (514) 288 6588
E-mail: secretariat@biodiv.org
Web site: www.biodiv.org

United Nations Environment Programme
Division of Environmental Conventions/IUC
International Environment House
35, chemin des Anémones
1219 Chatelaine, Switzerland
Phone: +41-22-917-8242/8196
Fax: +41-22-717-9283
Email: iuc@unep.ch
Web site: www.unep.ch/conventions

To obtain information on national reports submitted by governments under the Convention, contact your national government’s focal point, usually with the ministry responsible for environment or natural resources. National reports are also available electronically on the Convention’s web site at www.biodiv.org.
Our Local Habitat: The Sonoran Desert
**The Sonoran Desert**

**Background Information**

**What Is A Desert?**
We often hear of the desert as being a “harsh environment” where plant and animal life must “struggle to survive.” To humans, the desert heat and drought do appear to be harsh, and desert life does seem to be a struggle. However, desert species are adapted to desert conditions. Thousands of organisms thrive here. If the desert environment were hostile to life, life here would not exist.

The common denominator of all deserts is a lack of usable water. Availability of water is modified by seasonal and yearly fluctuations in length and intensity of rains, rate of evaporation, and the nature of the soil. What truly characterizes a desert is not how much annual rainfall is received, but the ratio of precipitation to evapotranspiration. Evapotranspiration is the process by which water is lost from the earth’s surface via evaporation of free-standing water and transpiration (the release of water vapor) through plants. In a desert, precipitation is much less than potential evapotranspiration. Other characteristics of deserts include intense sunlight, unpredictable and varying amounts of annual rainfall, windy conditions, and great variations between day and night temperatures.

What keeps precipitation away? The air currents passing over the land must be either dry or unable to release their moisture. Vertical motion of the air currents influences the amount of precipitation. As air moves downward it becomes warmer and drier, interfering with potential rain; as air rises it becomes cooler and the moisture it contains condenses, resulting in rain.

The world’s deserts are categorized into two main classifications based on the conditions that create them: horse latitude deserts and rain shadow deserts.

---

**Horse Latitudes**

**Horse Latitude or High Pressure Zone.**
At 30 degrees latitude in both the northern and southern hemispheres, the west coasts of all continents have deserts. These are caused by high pressure zones which result from warm, dry descending air (fig. 1). This downward motion of dry air prevents precipitation.

---

*Fig. 1*
Rain Shadow or Orographic Effect.
Moist air crossing a land mass loses its moisture while passing over mountains (fig. 2). As this air moves upward, it cools and the moisture it contains condenses dropping precipitation on the windward slope. The air is dry by the time it reaches the leeward side resulting in desert conditions.

The Sonoran Desert is a combination of a rain shadow desert in the northern limits and horse latitude desert at 30 degrees.

The North American Deserts
The North American Desert system consists of some 440,000 square miles in the western United States and northern Mexico. It is composed of four deserts that differ somewhat in climate and vegetation. Arizona is the only state in both countries in which all four can be found (fig. 3).
Sonoran Desert – The Sonoran Desert covers approximately 100,000 square miles and most of it is a low, hot desert with an elevation ranging from 3,500 feet to below sea level (fig. 4). Winters are mild and summers are hot. Precipitation varies in different regions, ranging from 1-14 inches (2.5-36 cm). Rainy seasons also vary; the eastern section receives summer rains, the northwestern portion receives winter rains, and the northeastern portion receives bi-seasonal rainfall (both in the late summer and winter).

The Sonoran Desert is quite lush when compared to most other deserts of the world. Its vegetation is visually dominated by columnar cacti (saguaro and organ pipe) and legume trees (mesquite, palo verde, acacia, etc.). The Sonoran Desert is diverse, containing more than 2,000 species of flowering plants alone.

The Sonoran Desert has been divided into six subdivisions, based primarily on vegetation differences.

Life in the Desert

The Sonoran Desert contains a diversity of plant and animal life adapted to thrive in the desert. An adaptation is any physical, physiological or behavioral trait or characteristic that enables an organism to survive and reproduce in its environment. Desert creatures have evolved a variety of drought- and heat-reducing adaptations. These include heat avoidance, heat reduction, heat tolerance and drought tolerance. Examples of these adaptations exhibited by different groups of animals and plants are described in the activities and student readings that follow.
You could easily recognize a desert even if you were blindfolded. You would discover that you could walk fairly long distances without bumping into plants, and when you did the encounter would likely be painful. Even standing still you would have unmistakable clues about your location. You'd feel the arid atmosphere pulling moisture out of your body and experience a sensation of pressure on your skin from the intense sunlight. On really hot, dry days you could smell pungent, aromatic terpenes and oils exuded by the parched vegetation.

With the blindfold removed, you would see that most desert plants also look different from those in other habitats - they are often spiny, almost always tiny-leafed, and rarely "leaf green". Many have bold, sculptural growth forms characterized by swollen stems or starkly exposed stems unconcealed by foliage. At the other extreme is a unique desert growth form that landscape architect Iain Robertson calls "diaphanous plants". The stems and foliage of these plants are so fine-textured and sparse that the eye tends to look right through them.

These tactile, olfactory, and visual experiences offer clues to desert plants' adaptations to their rigorous environment. Before exploring these special characteristics, it is important that you understand something about plant structures, functions, and classification.

**Basic Plant Anatomy and Classification**

Many people mistakenly identify ocotillos, agaves, African euphorbias, and numerous other plants as cacti because of their succulent or spiny stems, when in fact these plants are not related to each other or to cacti. Frequently plants (and animals) are similar to each other in outward appearance because their ancestors have adapted to the same environmental challenges by evolving similar forms or structures. This similarity in response to environment, despite lack of common recent ancestors, is known as convergent evolution. The very similar outward appearance of some New World cacti and Old World succulent euphorbias is an excellent example.

Unlike overall form or vegetative structures, the sexual parts of plants (flowers and fruits) are reliable indicators of interrelationships and means of identification. Flowers must function successfully if a plant is to reproduce. Therefore the floral structures tend to remain more consistent within a species than do vegetative parts. Floral structures also form complex patterns that are more readily traceable as plants evolve. The parts of flowers and fruits are also easier to identify and describe than the vegetative organs (leaves, stems, and roots). Moreover, qualitative vegetative characters are hard to describe precisely even when the overall appearance (gestalt) is distinctive. For example, nearly every hiker knows poison ivy on sight. But try to describe the foliage so precisely that someone who has never seen the plant can distinguish it from skunkbush (*Rhus trilobata*). It's quite difficult to delineate the leaves' different shades of green, degrees of hairiness, and the scalloping of the margins, especially if you lack the minutely-detailed vocabulary of the botanist. For example, the terms pubescent, puberulent, lanate, villous, hirsute, hirsutulous, ciliate, tomentose, strigose, pilose, and hispid are just some of those used to describe different kinds and degrees of hairiness. Vegetative parts are also more plastic; that is, they vary greatly - even in the
same individual - under environmental influences. The leaves of brittlebush grow much larger and greener in shade or during rainy periods than in sun or in drier conditions. (See photo on page 131; see also species account.)

The complex parts of flowers and fruits are arranged in distinctive patterns that can be characterized exactly. Petals, stamens, and other structures can be counted and their lengths and widths measured (and these are usually less variable than the dimensions of leaves). The point of attachment of the stamens to the petals (or other parts) can be described unambiguously. For example, a flower that has many (more than ten) petals and sepals that intergrade into one another, many stamens (usually hundreds), a two- to multi-lobed stigma, and an ovary enveloped in stem tissue may be unequivocally identified as belonging to a member of the cactus family. All 2000 species of cacti possess some variation of this basic pattern, and no other plant group does.

To recognize floral patterns you must be able to identify the parts of a flower. The drawing on page 131 shows the anatomy of a generalized flower.

Flower Anatomy, from Outside to Inside

In the game "Twenty Questions" players attempt to identify an unknown by asking the person who knows the answer a series of yes-or-no questions. If done well, twenty questions is sufficient to eliminate every other possibility in the world and leave the correct answer standing. Assume, for example, that the unknown thing is a dog. First question: "Is it a concept?" (No; therefore it's an object.) Second question: "Is it alive?" (Yes.) Third question: "Is it a plant?" (No). Fourth question: "Is it a vertebrate?" (Yes). Fifth question: "Is it an herbivore?" (No.) The enormous inventory of the universe has been narrowed to a very short list in only five questions.

Botanists identify plants (and zoologists, animals) unknown to them with a Twenty Questions-like procedure called a dichotomous key (or simply, key). A key is a nested series of dual choices that quickly narrows the possibilities to a single species. For example, the first pair of choices might ask you whether the flower has three petals versus four or five. Each of the two possible answers leads to another pair of choices, and so on, until you have identified your quarry out of 300,000 species of flowering plants. But before you can use such a key effectively, or before you can describe your unknown to someone who will identify it for you, you must know the parts of the flower and plant you are examining.

The sepals collectively make up the calyx. They enclose all other flower parts in the bud, usually completely concealing the rest of the flower until it opens. The petals collectively make up the corolla. Petals are frequently the visual advertising banner that attracts pollinators. Petals and sepals look similar in many flowers, such as in lilies and agaves. By definition the sepals are the parts on the outside; petals are typically concealed in the bud stage. When sepals and petals can't be readily distinguished, they are called tepals.

The corolla and calyx make up the perianth. The perianth parts may be separate or fused together for part or all of their length. Often there is only one series of perianth parts. Of necessity these must be on the outside and therefore they are sepals, even if they are large and colorful.
The female part of a flower is the pistil, composed of stigma, style and ovary (also called ovulary). The ovary contains ovules, which develop into seeds when fertilized by the sperm in pollen. Seeds are plant embryos encased in a protective membrane, usually along with stored energy to fuel germination. If the ovary is visible beneath the calyx, it is said to be inferior. It is superior if you must look inside the flower to see it (that is to say, it is above the calyx).

The male part of a flower is the stamen, composed of the anther and the filament. Anthers produce pollen grains, which contain sperm cells.

Photosynthesis

Chlorophyll is one of the most consequential chemicals in the biosphere. Nearly all life on the planet depends on it. Living organisms seem to defy the law of entropy, the universal tendency toward increasing disorder in a closed system. By using energy acquired from outside they prevent themselves - temporarily - from dying and disintegrating into simple, dissociated molecules (becoming disordered). A small number of species derive their energy from metabolizing sulfur compounds. All others, including all the organisms that we encounter in everyday life, depend on solar energy (light) to maintain their orderly existence. Light, however, is unmanageable; it can't be concentrated and stored for later use. (Outside of science fiction there is no such thing as a photon battery). Enter photosynthesis. Green plants use light energy to combine low-energy molecules (carbon dioxide and water) into high-energy molecules (carbohydrates), which they accumulate and store as energy reserves. Chlorophyll (the green pigment in plants) is the only known substance in the universe that can capture volatile light energy and convert it into a stable form usable for biological processes (chemical energy).

Almost without exception living organisms, plants, animals, and even fungi and bacteria, obtain energy for sustaining life from carbohydrates (sugars and starches) by the metabolic process of aerobic respiration. ("Respiration" is colloquially and medically used to mean breathing. The mechanical act of breathing, however, is only the first step in the physiological process of respiration.) Respiration is the chemical pathway through which carbohydrate is broken down (oxidized) into carbon dioxide and water, releasing the energy stored in the carbohydrate molecules. This is represented by the formula:

\[ \text{Carbohydrate} + \text{O}_2 \rightleftharpoons \text{H}_2\text{O} + \text{CO}_2 + \text{Energy} \]

The multiple arrows indicate many sequential chemical reactions.

Green plants manufacture carbohydrates by photosynthesis. Animals acquire their carbohydrates by eating plants or other animals. Photosynthesis is somewhat the reverse of respiration - carbon dioxide and water are combined to form larger molecules of carbohydrate, with the addition of energy from sunlight:

\[ \text{H}_2\text{O} + \text{CO}_2 + \text{Energy} \rightleftharpoons \text{Carbohydrate} + \text{O}_2 \]

Water is absorbed through the roots, and CO2 diffuses into the leaves through the stomates (valved pores in leaf and stem surfaces). The plant joins several carbon dioxide molecules and adds hydrogen atoms split from water molecules to form molecules of sugar (simple carbohydrate). Surplus oxygen atoms from the water molecules are released through the stomates as oxygen gas (O2).

When you see the word 'carbo-hydrate', think 'stored energy' and 'calories'. Plants store energy for long-term use in the form of starch, which is a complex carbohydrate consisting of long chains of sugar molecules. When a plant needs energy to grow new leaves or flowers, it does exactly what animals do - it respirates carbohydrate to release the stored energy. The complex respiratory pathway of scores of individual chemical reactions is nearly identical in all life forms: bacteria, mushrooms, saguaros, coyotes, and even in the highest life forms such as toads.
In contrast to plants, animals use fat as their main energy store; it has twice the number of calories per gram as do carbohydrate and protein. When animals in need of energy run low on the small amount of carbohydrate stored in the liver or circulating in the blood, they convert fat (or protein, if they run out of fat) into carbohydrate and then respire it.

The most common form of photosynthesis creates a 3-carbon sugar as its first stable product, so it's called C3 photosynthesis. Other sugars with more carbon atoms are later synthesized from this first one. More than 90 percent of all plant species use C3 exclusively, but there are two specialized supplementary variations.

One variant is called C4 photosynthesis because the first stable product is a 4-carbon sugar. Plants with C4 metabolism actively transport carbon dioxide to localized bundles of photosynthetic tissue. This process offers improved efficiencies under hot, sunny conditions. C4 plants use carbon dioxide more efficiently (by bypassing photorespiration) and lose less water through transpiration (water evaporated from inside plants) per unit of carbohydrate made. The overall result is that C4 plants can grow much faster under high temperatures than most C3 plants. The majority of summer-growing grasses in warm climates are C4. So are many other summer-growing plants, especially weeds (invasive pioneer plants) that seem to spring up overnight, such as pigweed (Amaranthus spp.) and summer spurs (Euphorbia hyssopifolia and others), as well as devil's claw (Proboscidea spp.), and many saltbushes (Atriplex spp.). Only about 3 percent of all the Earth's plant species are known to use C4, but a number of them are vital crops, such as corn, sorghum, and sugar cane. Another variant of photosynthesis, CAM, is discussed under the succulence section of this chapter on page 135.

Coping with Desert Climate

The impression that the desert environment is hostile is strictly an outsider's viewpoint. Adaptation enables indigenous organisms not merely to survive here, but to thrive. Furthermore, specialized adaptations often result in a requirement for the seasonal drought and heat. For example, the saguaro, well adapted to its subtropical desert habitat, cannot survive in a rain forest or in any other biome, not even a cold desert. In these other places it would rot, freeze, or be shaded out by faster growing plants.

Aridity is the major - and almost the only - environmental factor that creates a desert, and it is this functional water deficit that serves as the primary limitation to which desert organisms must adapt. Desert plants survive the long rainless periods with three main adaptive strategies: succulence, drought tolerance, and drought evasion. Each of these is a different but effective suite of adaptations for prospering under conditions that would kill plants from other regions.

Succulence

As a group succulents are the most picturesque desert plants. They capture our attention because they look nothing like the familiar plants of the temperate zone where most people live. Their vernacular names suggest how they command our attention: elephant tree, boojum, jumping cholla, creeping devil, and shindagger. Spanish names translate into equally colorful terms such as dragon's blood, child-killer, and old man's head. Even some scientific names are inspired by the plants' characteristics: Ferocactus (as in ferocious), Opuntia molesta (the molesting-spined cactus), O. invicta (the invincible point), and Agave jaiboli (as in a highball cocktail, because liquor is made from it).

Succulent plants store water in fleshy leaves, stems or roots in compounds or cells from which it is not easily lost (see photo on page 135). All cacti are succulents, as are such non-cactus desert dwellers as agaves, aloes, elephant trees, and many euphorbias. Several other adaptations are essential for the water-storing habit to be effective.
GETTING WATER
Succulents must be able to absorb large quantities of water in short periods, and they must do so under unfavorable conditions. Because roots take up water by passive diffusion, succulents can absorb water only from soil that is wetter than their own moist interiors. Desert soils seldom get this wet and don't retain surplus moisture for long. Desert rains are often light and brief, barely wetting the top few inches (centimeters) of soil, which may dry out after just a day or two of summer heat. To cope with these conditions, nearly all succulents have extensive, shallow root systems. A giant saguaro's root system is just beneath the soil surface and radiates as far as the plant is tall. The roots of a two-foot-tall cholla in an extremely arid site may be thirty feet (9 m) long. Most succulents, in fact, rarely have roots more than four inches (10 cm) below the surface and the water-absorbing feeder roots are mostly within the upper 1/2 inch (1.3cm). Agaves are an exception in lacking extensive root systems; most of the roots don't extend much beyond the spread of the leaf rosette. Instead, the leaves of these plants channel rain to the plants' bases.

CONSERVING WATER
A succulent must be able to guard its water hoard in a desiccating environment and use it as efficiently as possible. The stems and leaves of most species have waxy cuticles that render them nearly waterproof when the stomates are closed. Water is further conserved by reduced surface areas; most succulents have few leaves (agaves), no leaves (most cacti), or leaves that are deciduous in dry seasons (elephant tree Bursera spp., boojum Fouquieria columnarisp). The water is also bound in extracellular mucilages and inulin compounds that hold tightly onto the water.

Many succulents possess a water-efficient variant of photosynthesis called CAM, an acronym for Crassulacean Acid Metabolism. The first word refers to the stonecrop family (Crassulaceae) in which the phenomenon was first discovered. (Dudleya is in this family, as are hen-and-chickens and jade plant.) cam plants open their stomates for gas exchange at night and store carbon dioxide in the form of an organic acid. During the day the stomates are closed and the plants are nearly completely sealed against water loss; photosynthesis is conducted using the stored carbon dioxide. At night the temperatures are lower and humidity higher than during the day, so less water is lost through transpiration. Plants using CAM lose about one-tenth as much water per unit of carbohydrate synthesized as do those using standard C3 photosynthesis. But there is a trade-off: the overall rate of photosynthesis is slower, so CAM plants grow more slowly than most C3 plants. (An additional limitation is the reduced photosynthetic surface area of most succulents compared with "ordinary" plants.)

The equilibrium between gaseous carbon dioxide and the organic acid is dependent on temperature. Acid formation (carbon dioxide storage) is favored at cool temperatures; higher temperatures stimulate release of carbon dioxide from the acid. Thus CAM works most efficiently in climates that have a large daily temperature range, such as arid lands. Cool nights allow much carbon dioxide to be stored as acid, and the warm days cause most of the carbon dioxide to be released for photosynthesis. (A note of interest: A plant in CAM mode will store enough acid to impart a sour taste in early morning; the flavor becomes bland by afternoon when the acid is used up. But don't taste indiscriminately--many succulents are poisonous!)

Many succulents possess CAM, as do semisucculents such as some yuccas, epiphytic (growing on trees or rocks) orchids, and xerophytic (arid-adapted) bromeliads. Exceptions are stem succulents with deciduous, non-succulent leaves, such as elephant trees (Bursera spp.), limberbushes (Jatropha spp.), and desert roses (Adenium spp.). Succulents from hot, humid climates that lack substantial daily temperature fluctuations also usually do not use CAM. Some succulents, such as Agave deserti, can switch from CAM to C3 photosynthesis when water is abundant, allowing faster growth. Over five percent of all plant species spread among thirty or more plant families are known to use CAM.
Another crucial attribute of CAM plants is their idling metabolism during droughts. When CAM plants become water-stressed, the stomates remain closed both day and night and the fine (water-permeable) roots are sloughed off. The plant's stored water is essentially sealed inside and gas exchange greatly decreases. However, a low level of respiration (oxidation of carbohydrate into water, carbon dioxide and energy) is carried out within the still-moist tissues. The carbon dioxide released by respiration is recycled into the photosynthetic pathway to make more carbohydrate, and the oxygen released by photosynthesis is recycled for respiration. Thus the plant never goes completely dormant but is metabolizing, slowly idling. (This sounds like perpetual motion, but it isn't. The recycling isn't 100 percent efficient, so the plant will eventually exhaust its resources.) Just as an idling engine can rev up to full speed more quickly than a cold one, an idling CAM plant can resume full growth in twenty-four to forty-eight hours after a rain. Agaves can sprout visible new roots just five hours after a rain, whereas it may take a couple of weeks for a dormant nonsucculent shrub to resume full metabolic activity. Therefore, succulents can take rapid and maximum advantage of the soil moisture from a summer rain before it quickly evaporates. The combination of shallow roots and the CAM-idling which allows rapid response enables succulents to benefit from rain even in amounts less than 0.5 inch (6 mm).

PROTECTION

Stored water in an arid environment requires protection from thirsty animals. Most succulent plants are spiny, bitter, or toxic, and often all three. Some unarmed, nontoxic species are restricted to inaccessible locations. Smooth prickly pear (Opuntia phaeacantha var. laevis) and live-forever (Dudleya spp.) grow on vertical cliffs or within the canopies of armored plants. Still others rely on camouflage; Arizona night-blooming cereus (Peniocereus greggii) closely resembles the dry stems of the shrubs in which it grows.

These adaptations are all deterrents that are never completely effective. Evolution is a continuous process in which some animals develop new inheritable behaviors to avoid spines or new metabolic pathways to neutralize the toxins of certain species. In response the plants are continually improving their defenses. For example, packrats can handle even the spiniest chollas and rarely get stuck. They also eat prickly pear for water and manage to excrete the oxalates which could clog the kidneys of some other animals. Toxin-tolerant insects often incorporate their host plant's toxins into their own tissues for protection against their predators.

Drought Tolerance

Drought-tolerant plants often appear to be dead or dying during the dry seasons. They're just bundles of dry sticks with brown or absent foliage, reinforcing the myth that desert organisms are engaged in a perpetual struggle for survival. They're simply waiting for rain in their own way, and are usually not suffering or dying any more than a napping dog is near death.

Drought tolerance or drought dormancy refers to desert plants' ability to withstand desiccation. A tomato plant will wilt and die within days after its soil dries out. But many nonsucculent desert plants survive months or even years with no rain. During the dry season the stems of brittlebush and bursage are so dehydrated that they can be used as kindling wood, yet they are alive. Drought-tolerant plants often shed leaves during dry periods and enter a deep dormancy analogous to torpor (a drastic lowering of metabolism) in animals. Dropping leaves reduces the surface area of the plant and thus reduces transpiration. Some plants that usually retain their leaves through droughts have resinous or waxy coatings that retard water loss (creosote bush, for example).

The roots of desert shrubs and trees are more extensive than are those of plants of the same size in wetter climates. They extend laterally two to three times the diameter of the canopy. Most also exploit the soil at greater depths than the roots of succulents. The large expanses of exposed ground between plants in deserts are usually not empty. Dig a hole almost anywhere except in active sand dunes or the most barren desert
pavement and you are likely to find roots. Rooting depth controls opportunities for growth cycles. In contrast to the succulents' shallow-rooted, rapid-response strategy, a substantial rain is required to wet the deeper root zone of shrubs and trees. A half-inch is the minimum for even the smaller shrubs; more for larger, deeper-rooted plants. It takes a couple of weeks for dormant shrubs such as brittlebush (*Encelia farinosa*) and creosote bush (*Larrea tridentata*) to produce new roots and leaves and resume full metabolic activity after a soaking rain. The tradeoff between this strategy and that of succulents is that once the deeper soil is wetted, it stays moist much longer than the surface layer; the deeper moisture sustains growth of shrubs and trees for several weeks.

Mesquite trees (*Prosopis* spp.) are renowned for having extremely deep roots, the champion reaching nearly 200 feet. But these riparian specimens are not drought-tolerating trees, their roots are in the water table. Most large floodplain mesquites die if the water table drops below forty feet, and mesquites growing away from waterways remain short and shrubby. No desert plant is known to use very deep roots as a primary strategy for survival. In fact, the root systems of most trees - including mesquites - are mostly confined to the upper three feet of soil. Few rains penetrate deeper than this, and at greater depths there is little oxygen to support root respiration.

In contrast to succulents that can take up water only from nearly saturated soil, drought tolerant plants can absorb water from much drier soil. A creosote bush can obtain water from soil that feels dust-dry to the touch. Similarly these plants can continue to photosynthesize with low leaf-moisture contents that would be fatal to most plants.

Some plants in this adaptive group are notoriously difficult to cultivate, especially in containers. It seems paradoxical that desert ferns and creosote bushes, among the most drought-tolerant of desert plants, can be kept alive in containers only if they are never allowed to dry out. The reason is that these plants can survive drought only if they dry out slowly and have time to make gradual physiological adjustments. If a potted plant misses a watering, the small soil volume dries out too rapidly to allow the plant to prepare for dormancy, so it dies. Researchers showed that some spike mosses (*Selaginella* spp.) must dehydrate over a five to seven day period. If they dry more rapidly they lack time to adjust, and if drying takes longer than a week they exhaust their energy reserves and starve to death. (*Selaginella lepidophylla* from the Chihuahuan Desert is widely sold as a novelty under the name resurrection fern. Rehydration and resumption of active life takes only a few hours.)

**Drought Evasion**

Interstate 40 from Barstow to Needles, California traverses some of the emptiest land in the West. It dashes as straight as it can through 130 miles (200 km) of dry valleys that are almost devoid of human settlements. The vegetation is simple, mostly widely-scattered creosote bushes. It's difficult to tell if you're driving through the Mohave or Sonoran desert. The small, rocky mountain ranges interrupting the valleys beckon to true desert lovers, but the drive is just plain bleak to most folks. The exits on this freeway average ten miles (16 km) apart and connect to two-lane roads that shoot straight over the distant horizon with no visible destinations. You rarely see a vehicle on any of them.

Frequent travelers on this freeway become accustomed to its monotony until they think they know what to expect. The creosote bush may turn green if there has been a rain; ocotillo always flowers in April; most of the time it's just brown gravel and brown bushes. Then one spring travelers were astonished to discover the ground between the bushes literally carpeted with flowers. It happened in March 1998, when for three weeks the freeway bisected a nearly unbroken blanket of desert sunflowers forty miles long and ten miles wide. At every exit-to-nowhere several cars and trucks were pulled off and people wandered through the two-foot-deep sea of yellow. Those with long memories may have recalled that the same thing happened in 1978. Perhaps they wondered where these flowers came from, and where they were during the
intervening twenty years. Those desert sunflowers (*Geraea canescens*) were annual wildflowers, plants that escape unfavorable conditions by "not existing" during such periods. Annuals complete their life cycles during brief wet seasons, then die after channeling all of their life energy into producing seeds. Seeds are dormant propagules with almost no metabolism and great resistance to environmental extremes. (A propagule is any part of a plant that can separate from the parent and grow into a new plant, for example, a seed, an agave aerial plantlet, a cholla joint.) Seeds wait out adverse environmental conditions, sometimes for decades, and will germinate and grow only when specific requirements are met.

Wildflower spectacles like the one described above are rare events. Mass germination and prolific growth depend on rains that are both earlier and more plentiful than normal. The dazzling displays featured in photographic journals and on postcards occur about once a decade in a given place. In the six decades between 1940 and 1998 there have been only four documented drop-everything-and-go-see-it displays in southern Arizona: 1941, 1978, 1979, and 1998. During that period only the displays of 1978 and 1998 were widespread throughout both the Sonoran and Mohave deserts.

Annuals in the Sonoran Desert can be divided into three groups, based on time of germination and flowering. Winter-spring species are by far the most numerous. The showy wildflowers that attract human attention will germinate only during a narrow window of opportunity in the fall or winter, after summer heat has waned and before winter cold arrives. In most of the Sonoran Desert this temperature window seems to occur between early October and early December for most species. During this window there must be a soaking rain of at least one inch (2.5 cm) to induce mass germination. This combination of requirements is survival insurance: an inch of rain in the mild weather of fall will provide enough soil moisture that the resulting seedlings will probably mature and produce seeds even if almost no more rain falls in that season. (Remember that one of the characteristics of deserts is low and undependable rainfall.) If the subsequent rainfall is sparse, the plants remain small and may produce only a single flower and a few seeds, but this is enough to ensure a future generation. There is still further insurance: even under the best conditions not all of the seeds in the soil will germinate; some remain dormant. For example, a percentage of any year's crop of desert lupine seeds will not germinate until they are ten years old. The mechanisms that regulate this delayed germination are not well understood.

The seedlings produce rosettes of leaves during the mild fall weather, grow more slowly through the winter (staying warm in the daytime by remaining flat against the ground), and bolt into flower in the spring. Since the plants are inconspicuous until they begin the spring bolt, many people mistakenly think that spring rains produce desert wildflower displays.

There is a smaller group of annual species that grow only in response to summer rains. Annual devil's claw (*Proboscidea parviflora*) and Arizona poppy (*Kallstroemia grandiflora*) are among the few showy ones.

A third group consists of a few opportunistic species which will germinate in response to rain at almost any season. Most of these lack showy flowers and are known only to botanists, but desert marigold (*Baileya multiradiata*) is a conspicuous exception; it is actually not an annual, but rather a short-lived perennial in most of its range. A few species of buckwheats (*Eriogonum*) germinate in fall or winter and flower the following summer.

The annual habit is a very successful strategy for warm-arid climates. There are no annual plants in the polar regions or the wet tropics. In the polar zones the growing season is too short to complete a life cycle. In both habitats the intense competition for suitable growing sites favors longevity. (Once you've got it, you should hang onto it.) Annuals become common only in communities that have dry seasons, where the perennials are widely spaced because they must command a large soil area to survive the drier years. In the occasional wetter years, both open space and moisture are available to be exploited by plants that can do so
rapidly. The more arid the habitat, the greater the proportion of annual species in North America. (The percentage decreases in the extremely arid parts of the Saharan-Arabian region.) Half of the Sonoran Desert's flora is comprised of annual species. In the driest habitats, such as the sandy flats near Yuma, Arizona up to ninety percent of the plants are annuals.

Winter annuals provide most of the color for our famous wildflower shows. Woody perennials and succulents can be individually beautiful, but their adaptive strategies require them to be widely-spaced, so they usually don't create masses of color. A couple of exceptions are brittlebush when it occurs in pure stands, and extensive woodlands of foothill palo verde (*Cercidium microphyllum*). The most common of the showy winter annuals that contribute to these displays in southern Arizona are Mexican gold poppy (*Eschscholtzia mexicana*), lupine (*Lupinus sparsiflorus*), and owl-clover (*Castilleja exserta*, formerly *Orthocarpus purpurascens*).

One of the contributing factors to the great number of annual species is niche separation. (A niche is an organism's ecological role; for example, sand verbena is a butterfly-pollinated winter annual of sandy soils.) Most species have definite preferences for particular soil textures, and perhaps soil chemistry as well. For example, in the Pinacate region of northwestern Sonora there are places where gravels of volcanic cinder are dissected by drainage channels or wind deposits of fine silt. In wet years *Nama demissum* (purple mat) grows abundantly on the gravel and the related *Nama hispidum* (sand bells) on the silt. I have seen the two species within inches of each other where these soil types meet, but not one plant of either species could be found on the other soil. There are specialists in loose sand such as dune evening primrose (*Oenothera deltoides*) and sand verbena (*Abronia villosa*), and others are restricted to rocky soils, such as most caterpillar weeds (*Phacelia* spp.). This phenomenon of occupying different physical locations is spatial niche separation.

Another diversity-promoting phenomenon is temporal niche separation: the mix of species at the same location changes from year to year. Seeds of the various species have different germination requirements. The time of the season (which influences temperature) and quantity of the first germination-triggering rain determines which species will dominate, or even be present at all in that year. Of the three most common annuals of southern Arizona listed above, any one may occur in a nearly pure stand on a given hillside in different years, and occasionally all three are nearly equally abundant. This interpretation of the cause of these year-to-year variations is a hypothesis based on decades of empirical observation. Much more research is needed to discover the ecological requirements of most species of desert annuals. And of course the Sonoran Desert's two rainy seasons provide two major temporal niches. Summer and winter annuals almost never overlap.

The dramatic wildflower shows are only a small part of the ecological story of desert annuals. For each conspicuous species there are dozens of others that either have less colorful flowers or don't grow in large numbers. Every time the desert has a wet fall or winter it will turn green with annuals, but it will not always be ablaze with other colors. One of the most common winter annuals is desert plantain (*Plantago insularis*). It usually grows only a few inches tall and bears spikes of tiny greenish flowers, but billions of plants cover many square miles in good years. The tiny seeds are covered with a soluble fiber which forms a sticky mucilage when wet by rain; this aids germination by retaining water around the seed and sticking it to the ground. A related species from India is the commercial source of psyllium fiber (*Metamucil*, for example). The buckwheat family (*Polygonaceae*) is well-represented. There are more than a score of skeleton weeds (*Eriogonum* spp.) and half as many spiny buckwheats (*Chorizanthe* spp.), most of which go unnoticed except by botanists (see species accounts). Fiddlenecks (*Amsinckia* spp., *Boraginaceae*) may grow in solid masses over many acres, but the tiny yellow flowers don't significantly modify the dominant green of the foliage. These more modest species produce more biomass than the showy wildflowers in most years, and thus form the foundation of a great food pyramid.
Some perennials also evade drought much as annuals do, by having underground parts that send up stems, leaves, and flowers only during wet years. Coyote gourd (Cucurbita digitata) and perennial devil's claw (Proboscidea althaeifolia) have fleshy roots that remain dormant in dry years. Desert larkspur (Delphinium parryi) is a perennial that has woody rootstocks but also sprouts only in wetter years. Desert mariposa (Calochortus kennedyi) and desert lily (Hesperocallis undulata) have bulbs that may remain dormant for several years until a deep soaking rain awakens them.

Our desert wildflower displays are in jeopardy from invasive exotic plants. Species such as Russian thistle (Salsola tragus, also called S. kali), mustards (especially Brassica tournefortii), filaree (Erodium cicutarium), and Lehmann's lovegrass (Eragrostis lehmannii) are more aggressive than most of the native annuals and are crowding them out in many areas where they have become established. Some are still increasing their geographic ranges with every wet winter. Disturbed sites such as sand dunes, washes (naturally disturbed by wind and water, respectively), roadsides, and livestock-grazed lands are particularly vulnerable to invasion by these aliens.

Combined Drought Adaptations

These three basic drought-coping strategies - succulence, drought tolerance, and drought avoidance - are not exclusive categories. Ocotillo behaves as if it were a CAM-succulent, drought deciduous shrub, but it is neither CAM nor succulent (see details in the species accounts). The genus Portulaca contains species that are succulent annuals. The seeds may wait for a wet spell to germinate, but the resulting plants can tolerate a moderate drought. The semisucculent yuccas have some water storage capacity, but rely on deep roots to obtain most of their water. Mesquite trees are often phreatophytes (plants with their roots in the water table), but some species can also grow as stunted shrubs on drier sites where ground water is beyond their reach.

Adaptations to Other Desert Conditions

Water scarcity is the most important, but not the only, environmental challenge to desert organisms. The aridity allows the sun to shine unfiltered through the clear atmosphere continuously from sunrise to sunset. This intense solar radiation produces very high summer temperatures which are lethal to nonadapted plants. At night much of the accumulated heat radiates through the same clear atmosphere and the temperature drops dramatically. Daily fluctuations of 40°F (22°C) are not uncommon when the humidity is very low.

Microphylly (the trait of having small leaves) is primarily an adaptation to avoid overheating; it also reduces water loss. A broader surface has a deeper boundary layer of stagnant air at its surface, which impedes convective heat exchange. A leaf up to 1/2 inch (10 mm) across can stay below the lethal tissue temperature of about 115°F (46°C) on a calm day with its stomates closed. A larger leaf requires transpiration through open stomates for evaporative cooling. Since the hottest time of year is also the driest, water is not available for transpiration. Non-succulent large-leafed plants in the desert environment would overheat and be killed. Desert gardeners know that tomatoes will burn in full desert sun even if well watered; their leaves are just too big to stay cool. Desert plants that do have large leaves produce them only during the cool or rainy season or else live in shaded microhabitats. There are a few mysterious exceptions, such as jimson weed (Datura wrightii) and desert milkweed (Asclepias erosa). Perhaps their large tuberous roots provide enough water for transpiration even when the soil is dry.

Leaf or stem color, orientation, and self-shading are still more ways to adapt to intense light and heat. Desert foliage comes in many shades, but rarely in typical leaf-green. More often leaves are gray-green,
blue-green, gray, or even white. The light color is usually due to a dense covering of trichomes (hairlike scales), but is sometimes from a waxy secretion on the leaf or stem surface. Lighter colors reflect more light (= heat) and thus remain cooler than dark green leaves. Brittlebush and white bursage leaves show no green through their trichomes during the dry season, while desert agave (Agave deserti) is light gray due to its thick, waxy cuticle. Other plants have leaves or stems with vertical orientations; two common examples are jojoba and prickly pear cactus. This orientation results in the photosynthetic surface facing the sun most directly in morning and late afternoon. Photosynthesis is more efficient during these cooler times of day.

Prickly pear pads will burn in summer if their flat surfaces face upward. Some cacti create their own shade with a dense armament of spines; teddy bear cholla (Opuntia bigelovii) is one of the most striking examples.

Pollination Ecology and Seed Dispersal of Desert Plants
(this portion of the chapter is also available in Spanish: Ecología de la polinización y dispersión de las semillas de las plantas del desierto)

Flowers are very useful for identifying plants and providing aesthetic pleasure for humans, but they have a more vital function - they are the sexual reproductive organs of plants. Many plants also have methods of asexual (vegetative) reproduction, which produces offspring that are genetically identical to the parent: root-sprouting (limberbush, palo verde, aspen), stolons and rhizomes (agaves, strawberries, many grasses), and aerial plantlets (some agaves, mother-of-millions, kalanchoe). All of the progeny of asexual reproduction are clones of their parent plants. (A clone is a group of organisms that are genetically identical; in the case of flowering plants each clone originates from a single seed.) Horticulturists have developed additional methods of plant cloning that are valuable in perpetuating superior varieties of plants: cutting, grafting, and tissue culture. The "Kadota" fig is a cultivar (contraction for cultivated variety) that has been propagated by cuttings for at least two millennia; it is described under a different name in the writings of Pliny the Younger.

In contrast, sexual reproduction combines half the genes from each of two parents, so sexually produced offspring are different from either of their parents and from one another. This variation is the raw material of natural selection which in turn results in evolution. A species that cannot reproduce sexually - there are quite a few among both plants and animals - is at greater risk of extinction if its environment changes, because it cannot adapt to new conditions.

Pollination is the transfer of pollen from an anther onto the stigma of a flower. The pollen then grows a tube that penetrates the style down to the ovary; sperm cells swim down the tube and fertilize the ova. Fertilized ova develop into seeds, which are the sexual propagules of flowering plants.

Outcrossing (pollination by pollen from another plant) is evolutionarily advantageous because the offspring are more variable than those from self-pollination. Variability increases plants' probability of surviving in an ever-changing environment. (But self-pollination is still sexual reproduction which results in different combinations of genes and therefore allows evolutionary change, as vegetative cloning does not.) Plants have many adaptations that increase the likelihood of outcrossing.

Because plants are rooted in the ground and can't get together to mate, they must employ an agent to transport pollen between plants. From this need widespread and complex kinds of mutualism (mutually beneficial interactions) have evolved between plants and animals. The pollen-transporting agent is frequently an insect or other flying animal. (Flying animals are more mobile than grounded species, and thus more likely to visit widely-separated plants.) In order to get pollinated, a flower must both make its
presence known (advertise), and provide an incentive (a reward) for an animal to make repeated visits to flowers of the same species. The advertisements are fragrance and/or conspicuous color. Two kinds of food are the usual reward. Nectar is a sugar solution that provides energy for flight. Flying requires much more energy than terrestrial locomotion. Pollen, besides being the male gene-bearer of a flower, is also rich in proteins essential for maintaining animal tissues and for raising young. In place of nectar some flowers offer oil (fat), another energy food. Others provide fragrances that the pollinator gathers to use for its own reproductive advertisement, and a few fascinating species employ deceit and provide no reward (see the species account on pipevine for an example).

The sugar in nectar and the protein in pollen are expensive to produce, so there is selective pressure to use these resources efficiently. It is important that animals other than the pollinators do not eat (steal) the nectar and pollen, and that the pollinators transport pollen to other flowers of the same species and deposit it in the right place. Natural selection has produced specialization: most plants with animal-pollinated flowers attract only a few species of animals which have the right size and behavior to reach the reward and pick up pollen. The more than 100 million years of coevolution between flowering plants and their pollinators has greatly contributed to the huge number of species in both kingdoms (300,000 flowering plants, 350 hummingbirds, and 15,000 known bees in the world). It also explains why there are so many different shapes and colors of flowers.

Flowers can be classified into several pollination syndromes according to their pollinators. (A syndrome is a set of characteristics associated with a specific phenomenon.) This is not the same classification as systematic taxonomy and does not reflect the evolutionary relationships among plants. Species in the same family or even the same genus may attract different pollinators.

The hummingbird pollination syndrome is one of the most easily recognized. Hummingbirds are large compared to most insects, almost unique in their ability to feed while hovering, and daytime-active; they have no sense of smell, but have long narrow beaks and tongues that can probe deep narrow tubes, and excellent color vision. Hummingbird flowers tend to be long-tubular, non-fragrant, sideways- or downward-facing, day-blooming, and brightly colored. Bees and most other animals cannot easily land on a hanging flower, and even if they succeed they cannot reach the nectar at the base of the narrow tube. There are common misconceptions that all hummingbird flowers are red and that hummingbirds can see only the warm colors of the spectrum. It is true that most hummingbird flowers in the temperate biomes are red, but in the tropics they come in many colors. The predominance of red in temperate hummingbird flowers may be a disincentive to bees. Bees are aggressive pollen collectors in temperate climates. But they cannot see red, so red flowers do not appear conspicuous to them.

Wind-pollinated plants make no investment in attracting animals; their flowers lack fragrance or showy parts. Many people would not recognize them as flowers at all. Prodigious quantities of pollen are released, an infinitesimal proportion of which lands on a receptive stigma of the same species. While this seems inefficient, it is obviously effective, judging from the successful groups of plants with this syndrome. Conifers, most riparian trees (such as willows and sycamores), oaks, and grasses are all wind-pollinated. Conifers and grasses are the dominant plants in the two biomes that bear their names. Grasses occur in most biomes and comprise the sixth largest family of plants with about 9000 species worldwide. Wind pollination is not always entirely passive (see the species account for jojoba).

Seed Dispersal

Seeds generally need to be transported some distance from the parent plant in order to find a suitable site for establishment. Some plants have wind-dispersed seeds, which are occasionally blown many miles from
their origins. This means of dispersal is common among pioneer plants (plants that are adapted to colonizing disturbed habitats). Because of their superior ability to invade newly-disturbed ground, pioneer plants comprise many of our agricultural and garden weeds. Moreover, most annual crops are domesticated pioneer plants. That’s why we need to plow (disturb) fields in order to grow them.

Many plants use animals to disperse their seeds in another complex coevolutionary process. Small, brightly colored fruits such as hackberry and boxthorn are offered as food for birds that swallow them whole. Other fruits such as those of hedgehog cacti are large and birds feed on them repeatedly. Some bird fruits are sticky, such as mistletoe berries; a few stick to the bird's bill until wiped off on a branch while others are successfully swallowed. The seeds of bird fruits are typically small and hard; they pass through birds' guts undamaged and may be deposited many miles from the parent plant.

Mammal-dispersed fruits tend to be larger, aromatic, not colorful (most non-primate mammals have poor color vision), and usually have larger seeds than bird fruits. The animal often transports the fruits a short distance (compared to the flying distances of many birds) to a safer place before eating the pulp and dropping at least some of the seeds. The seeds of coyote gourds (Cucurbita spp.) may be dispersed in this manner. Coyotes swallow the whole fruits of palm trees; they digest the thin pulp and excrete the hard seeds intact. Since seeds contain energy stores to nourish the germinating embryo, seeds themselves are also nutritious food for mammals and birds. Some plants offer their seeds without juicy pulp to attract mammals. Pocket mice and antelope squirrels gather the abundant seeds of foothill palo verdes and bury them as food caches for the dry season. The animals don't eat all that they bury, so some seeds remain in the ground and germinate when the rains come. (Birds that specialize in eating seeds, as opposed to fruits containing seeds, crush and digest the seeds and therefore do not disperse viable propagules.)

Even in the desert some seeds are water-dispersed. Blue palo verde (Cercidium floridum) grows mostly along washes. Flash floods disperse the very hard, waterproof seeds downstream, scarifying (abrating the surface of) them in the process. In the absence of scarification these seeds must weather in the ground for a few years before the seed coats become permeable and permit germination.

The timing of seed maturation is crucial for many plants. The less time seeds are present before they sprout, the greater is their chance of survival. The tropically derived plants in our region germinate with the summer rains. These species usually flower in spring and their fruits ripen shortly before the arrival of the summer rainy season. Palo verde and saguaro are examples. Other plants produce large quantities of seeds and rely on camouflage or burial in the soil to conceal some of them from hungry animals. Brittlebush, for example, flowers and seeds in spring, but the seeds germinate with fall rains. Annuals do the same.

Flowering Seasons in the Sonoran Desert

The Spring Flowering Season

The spring flowering season in the Arizona Upland subdivision spans from mid February to mid June with a peak from mid March to late April depending on rainfall and temperatures during the growing season. In the warmest areas of the Lower Colorado River Valley subdivision it is normally a couple of weeks earlier, though it sometimes starts as early as November. The different life forms which dominate at different times vary in their showyness and reliability. The early-blooming winter annuals can create an incredible display, but do so only rarely. Later-blooming species bloom more dependably, but mostly not in great masses of color. The progression of spring bloom described below is for average years near Tucson. It may be three weeks earlier or later depending on weather, elevation, and latitude.
WINTER ANNUALS such as poppy (*Eschscholtzia mexicana*), lupines (*Lupinus sparsiflorus* and others), and owl-clover (*Castilleja exserta*) create the vast carpets of color for which the Sonoran and Mohave deserts are so famous. This event may occur between late February and mid April, usually in mid March. Annuals are highly dependent on rainfall. Massive and widespread displays occur only about once a decade, when the winter rainy season is both earlier and wetter than normal. Good shows happen in localized areas every three or four years. A good bloom cannot be reliably predicted more than a week or two before it begins, and usually lasts at peak beauty for only two weeks. Seeing such a bloom requires being able to travel on short notice, and perhaps great distances. Death Valley may be spectacular in a year when Organ Pipe Cactus National Monument is poor. The high Mohave Desert may peak two or three weeks later than the lower-elevation and more southerly Sonoran Desert. A good bloom may occur in a remote area and remain undiscovered.

HERBACEOUS PERENNIALS AND SMALL SHRUBS such as penstemon (especially *Penstemon parryi*, shown here), brittlebush (*Encelia farinosa*), and fairy duster (*Calliandra eriophylla*) also require rain to bloom but are less sensitive to its timing. They are somewhat more dependable than the annuals, making a good show in about half of the years and peaking some time in March. These species usually grow as individuals or in small patches and do not create masses of color.

CACTI, because they store water, are fairly independent of rain. They bloom well nearly every year though wetter years produce more flowers. The greatest diversity of spring-blooming species can be seen in April. The cactus show continues as the abundant prickly pears bloom in early May, followed by saguaros from mid May to mid June.

TREES AND LARGE SHRUBS are fairly dependable bloomers, though flowers will be sparse in dry years. Creosote bush (*Larrea tridentata*) and whitethorn acacia (*Acacia constricta*, shown here) both bloom mainly in spring and sometimes again in summer. Blue palo verde (*Cercidium floridum*) turns bright yellow in late April, followed two weeks later by the much more abundant but paler yellow foothills palo verde (*C. microphyllum*). Desert ironwood trees (*Olneya tesota*) bloom heavily about every other year with masses of lavender flowers, usually in late May. The abundant ocotillo reliably produces spikes of red flowers throughout April. These species bloom about two weeks earlier in western Arizona.

SUMMARY

If you want to see the famous carpets of color, keep abreast of local news from Palm Springs to Tucson and from Death Valley to northern Mexico. Begin checking in late February and be ready to travel on short notice. You’ll find masses of annuals somewhere in this area about once every three or four years. If you want dependability and will settle for less quantity, success is almost guaranteed in the middle half of April.
The Summer Flowering Season

This season begins a few weeks after the first summer rain and continues into late fall. Though there are many beautiful species to be seen, there are rarely massive displays of color in this season, because the summer rains are more sporadic and localized than the winter rains and the soil dries rapidly in the heat.

SUMMER ANNUALS such as summer poppy (*Kallstroemia grandiflora*) and devil's claw (*Proboscidea parviflora*) germinate within a few days after the first soaking summer rain and begin to flower as soon as three weeks later. Chinchweed (*Pectis papposa*) is the most widely-adapted summer annual; it ranges from New Mexico into the central Mohave Desert where it is the only summer annual (summer rains are uncommon in the Mohave). It can form showy carpets of yellow when rains are abundant.

HERBACEOUS PERENNIALS AND SMALL SHRUBS bloom opportunistically if they get enough rain. Trailing four-o'clock (*Allionia incarnata*) and desert marigold (*Baileya multiradiata*) are nonseasonal, flowering in response to rain in all but the coldest months. Fairy duster will also bloom again in wet summers, but not as profusely as in spring. Sacred datura (*Datura wrightii*) is mainly a summer perennial though it may begin flowering as early as April in warmer areas. There are several woody shrubs that bloom in late fall. Most are composites such as turpentine bush (*Isocoma tenuisecta*) and desert broom (*Baccharis sarothroides*). Desert senna (*Senna covesii*) and Coulter hibiscus (*Hibiscus coulteri*) flower in response to any warm rain and peak in summer when most such rain occurs. Desert zinnia (*Zinnia pumila*) is truly biseasonal, flowering well in both rainy seasons.

CACTI include several summer-flowering species. The pincushion cactus *Mammillaria grahamii* makes buds during its previous growing season, then goes dormant during the dry season. The buds burst into bloom five days after each of the first two or three summer rains. The fishhook barrel cactus, *Ferocactus wislizeni*, is much larger than the pincushion and less dependent on rain; it flowers throughout August and September.

TREES AND LARGE SHRUBS are nearly all spring bloomers, but a few bloom again in summer if rains are generous. Whitethorn acacia (*Acacia constricta*) and velvet mesquite (*Prosopis velutina*) flower heavily in spring and often again in summer. Desert willow (*Chilopsis linearis*) flowers from spring through fall if it has enough water.

SUMMARY
Though the Sonoran Desert has two flowering peaks, there is almost always something in bloom. The only exceptions are after a hard winter freeze or during severe droughts.
Predicting Wildflower Blooms

Desert annual wildflower blooms are nearly impossible to predict for two reasons. First, the necessary conditions are not precisely known. Second, many interacting variables affect the phenomenon. Here is what we do know:

- **Spring-blooming annuals must germinate in the autumn.** This is a crucial fact that most people don't know. The "critical window" is probably between late September and early December, but differs with different species. The controlling environmental factor is temperature.
- **A triggering rain of at least one inch must occur during this autumn window,** the earlier the better after summer heat has waned. Rains at other times will seldom trigger germination of the showy-flowered species.
- **The triggering rain must be followed by regular rains** totaling at least an inch per month through March, a season total of at least five inches - seven or more are better.

In short, a really good wildflower bloom requires both an unusually early and an unusually wet winter rainy season. The rains must also be well spaced. Spectacular, widespread shows occur about once in ten years in the Sonoran and Mohave deserts. Good or better displays occur in localized areas perhaps every three or four years; these may be in remote regions and go unnoticed. However, even when all the above conditions are met, the bloom may be mediocre or poor. And occasionally a good bloom occurs when the above conditions appear not to have been met. The latter can happen when an unusually warm rain triggers germination in winter, but the short growing season usually precludes a really good show. Factors which are suspected of preventing a show include:

- a few weeks of warm, windy weather; the water stress triggers premature flowering;
- a cold winter that retards growth of the seedlings;
- high population levels of herbivores: rodents, rabbits, quail, or insects; and a wet preceding summer, resulting in thick growth of summer vegetation, which in turn prevents germination of winter annuals.

When it does happen, the peak typically lasts only two weeks at a given location, sometime between late February and mid April. Most often it happens in early to mid March.

Furthermore, only certain areas ever have mass displays; soil type and vegetation cover are important factors. The rocky and densely-vegetated Tucson Mountains rarely if ever have mass blooms, whereas Picacho Peak and the Tohono O’odham (Papago) Indian Reservation do fairly regularly.

The above information pertains only to annual wildflowers such as poppies, lupines, and owl-clover. Perennials are less fussy about the timing of rainfall. Thus a late but wet rainy season can still produce good blooms of penstemon, larkspur, brittlebush, and other perennials. Some plants such as palo verdes, ocotillo, and most cacti flower nearly every year regardless of rainfall. But it is the annuals alone that produce the desert's famous carpets of color.
The Invisible Larder

I conducted a wildlife survey in the Lower Colorado River Valley in the 1970s. The site had received almost no biologically effective rainfall for three years. Creosote bushes were almost the only plants present; they were widely-spaced and had shed most of their leaves. Yet in the kilometer (6/10 mile) long by fifty meter (150 foot) wide transect I trapped one pocket mouse overnight, and in the morning observed a whiptail lizard, a rock wren, and two black-throated sparrows. These are all resident species; not transitory migrants. What were they living on?

A persistent, large soil seed bank is an extremely important resource in arid habitats. It provides an unseen (by humans) food source for desert animals as well as survival insurance for plant species. The greater density of seed-eating animals and the abundance of decomposing microbes in the moist soils of wetter regions greatly shortsens the viability of seeds. In deserts, viable and nutritious seeds persist in large numbers through decades of drought. After a wet year there may be 200,000 seeds per square meter (square yard) of soil. Even after several dry years with little or no additional seed production there are still several thousand seeds per square meter, enough to sustain low populations of seed-eaters such as harvester ants, kangaroo rats, and sparrows. The whiptail was foraging for insects that fed on the seeds or plant detritus (partially decomposed organic matter) in the soil. As the statistician in the movie 'Jurassic Park' said, "Life will find a way".

Additional Readings


* Though these two books are found in childrens literature, they convey the essence of ecology better than any scientific treatise I have encountered.
Adaptations of Desert Amphibians & Reptiles

Thomas R. Van Devender
An excerpt from A Natural History of the Sonoran Desert

Amphibians and reptiles have many different adaptations that allow them to live in deserts, avoiding extremes in aridity, heat, or cold. The animals may be active only in certain seasons and at favorable times of the day. Many use the environment to actively regulate their body temperatures, preventing lethal extremes. And some are well adapted to the surfaces they live on— with modified appendages for burrowing or the capacity to run on, dive into, swim in or sidewind across loose sand.

Before vertebrate animals adapted to specific terrestrial habitats, such as deserts, they first had to adapt to living on land. The primary adaptations to life on land occurred in the Paleozoic 400 to 360 mya (million years ago) with the evolution of amphibians. Amphibians, a name derived from the Greek word amphibious (a being with a double life), live in fresh water as larvae and can move onto land as adults. In the amphibian’s metamorphosis from larva to adult, one can read the story of its evolution from lung fish: the larva uses gills to breathe and openings along its lateral line to sense its environment; in the adult these are lost, and lungs, limbs and digits develop. Aquatic larvae and thin permeable skin vulnerable to water loss and sunlight prevent amphibians from entirely living on land and limit their radiation into arid habitats. Although early amphibians had lumbered ashore in search of insects, vertebrates didn’t finally leave the water until later in the Paleozoic when the first reptiles evolved waterproof skin and an egg with membranes (amnion, chorion) to protect embryos from desiccation.

The evolutionary radiations of modern amphibians and reptiles, as well as of modern mammals and birds, began as the dinosaurs declined in the late Cretaceous (98-65 mya). Most general adaptations to aridity evolved in the dry seasons of tropical deciduous forests from the Eocene (about 45 mya) through the middle Miocene (15 mya), long before the deserts of North America came into being. The adaptations of Sonoran Desert endemics likely evolved in tropical deciduous forests or thornscrub. The uplift of the Sierra Madre Occidental by 15 mya changed weather patterns. Preadapted reptiles thrived as increasing aridity formed the Sonoran Desert by the late Miocene (8 mya).

Desert environments present great difficulties to amphibians. Tiger salamanders and lowland leopard frogs enter the desert only near permanent ponds, streams or springs. Tiger salamanders often become neotenic (retaining their larval forms) even reproducing as larvae, and only rarely metamorphosing into terrestrial adults.

The Sonoran Desert toad, desert spadefoot, northern casque-headed treefrog and others survive in the desert because of their abilities to excavate burrows as much as three feet deep where they spend nine or ten months at a time. Spadefoots and the northern casque-headed treefrogs have hardened areas, called spades, on their hind feet with which to dig. To prevent water loss in the burrows, spadefoots secrete a semipermeable membrane that thickens their skins, while the casque-headed treefrog forms a cellophane-like cocoon by shedding outer layers of skin. Spadefoots have a high tolerance for their own urea, since they do not excrete while in their burrows.

The ultimate challenge for desert amphibians is to reproduce in the temporary pools produced by highly sporadic and localized summer thunderstorms. Most breeding occurs at night with females
attracted to calling males. The desert spadefoots evolved an accelerated development rate - from egg to toadlet in less than two weeks! In southeastern California, where summer rainfall is less dependable, spadefoots emerge during the first storm, travel to ponds, call and breed, and gorge on lipid-rich, swarming termites, often in single night. The adults may have only enough fat reserves to survive for a year without feeding.

Primitive reptiles were able to radiate into drier habitats than amphibians because of the amniote egg with a leathery or hard shell, and because of their relatively impermeable skin with scales. Populations no longer were concentrated near water sources and embryos developed directly into small adults at hatching.

Since reptiles have thin skin with little insulation and most do not produce heat internally to fuel their metabolisms, adaptations to regulate body temperature (thermoregulation) are very important. Thermoregulation is possible because of complex relationships between body temperature, physiological processes (chemical reactions, hormone production, etc.) and behavior. Activity patterns change with the seasons, from midday in spring and fall to early morning and late afternoon in summer. Nocturnal reptiles such as the banded gecko and most snakes passively exchange heat with the air and soil. In contrast, diurnal lizards absorb heat by basking in the sun. Relatively uniform body temperatures are maintained in a number of ways: through the timing of daily activities, by shuttling in and out of shade and changing body orientation to the sun (insolation), by adjusting contact with the surface to regulate heat transfer (conduction), by changing color (dark skin absorbs energy faster), and so on. Additionally, some desert reptiles can tolerate quite high body temperatures; the desert iguana's active range, for example, is 100 to 108°F (38-42°C).

During times of environmental stress, desert reptiles spend long periods of inactivity in burrows, often borrowed from those dug by rodents or other mammals. During hibernation in winter and estivation in summer, animals in burrows have greatly reduced metabolic processes. They live on water and nutrients stored in their bodies, while wastes accumulate to potentially-toxic levels. Desert tortoises, for example, have a large urinary bladder that can store over 40 percent of the tortoise's body weight in water, urea, uric acid and nitrogenous wastes for months until they are able to drink. Urates are separated from water and can be eliminated in solid form, freeing water and ions to be reabsorbed. During extended droughts while the tortoises are inactive, they can reabsorb minerals from their shells to use in their metabolic processes. The giant Isla San Esteban and spiny chuckwallas on islands in the Gulf of California have a pair of lateral lymph sacs in the sides of their bodies that allow them to store extracellular fluid. Chuckwallas and Gila monsters, as well as the barefoot and western banded geckos store water in fatty tissue in their tails.

Species in the Lower Colorado River Valley of Arizona and California and the Gran Desierto of northwestern Sonora have a number of specializations for living in loose windblown sand. Sidewinders have evolved with an unusual form of locomotion where the body contacts the surface at only two points as it lurches along. The flat-tailed horned lizard and the Baja California legless lizard (a snakelike burrowing lizard about the size of a lead pencil, restricted to a small area on the western coast of Baja California) have lost the sand-collecting external ear openings present in most lizards. Several species, including the legless lizard, banded sand snake, and shovel-nosed snake, have small eyes, narrow heads, counter-sunk lower jaws, and very smooth scales - adaptations to swimming and breathing in loose sand. The fringe-toed lizard has pointed, fringe-like scales on the elongated toes of its hind feet to give it traction as it runs across dune surfaces. The wedge-shaped head, nasal valves, ringed eyelids, scaly ear flaps, and fine body scales allow this lizard to escape predators by diving and burrowing into sand.

Thus, amphibians and reptiles use a variety of mechanisms not merely to survive extreme heat and aridity but actually to thrive in hot, dry deserts. Virtually all of these adaptations were inherited from tropical ancestors before the late Miocene formation of the Sonoran Desert.
The Desert Adaptations of Birds & Mammals

Peter Siminski
An excerpt from A Natural History of the Sonoran Desert

Have you ever wondered how animals can live in a hostile desert environment? Water, so necessary for life processes, is often scarce. Temperatures, which range from freezing to well over 100°F (38°C), make maintaining a safe body temperature a constant challenge. Add to this the catch-22 of desert survival: an organism's need for water increases as temperature rises-available water usually decreases the hotter it gets. This might sound like an impossible situation, yet, as we'll see, desert birds and mammals have developed many adaptive strategies for coping with temperature extremes and limited water.

The primary strategy for dealing with high desert temperatures is avoidance-many mammals simply avoid the high daytime temperatures by being nocturnal or crepuscular (dusk- or dawn-active). A bobcat, for instance, is typically most active at dusk and dawn; a javelina is never active during the day in summer, but it may be in winter. Even day-active birds are most active at the cooler dawn. Many mammals, such as ringtails or kangaroo rats, are never active during the day.

Microclimates and Burrows

Another avoidance strategy is to seek out a cool microclimate. A cactus wren may simply rest quietly in the shade of a jojoba; a prairie falcon will nest on a ledge of a cool north-facing cliff and avoid the hot south face. A cool, deep crevice in the cliff face may be the daytime refuge of a pallid bat, while a ringtail is sleeping away the day in a jumble of rocks at the base of the cliff.

Some mammals create their own microclimates. A white-throated wood rat (or pack rat) builds a den made of desert litter-cholla joints, prickly pear pads, sticks, and stones-within a clump of prickly pear cactus. It looks a little like a trash heap and may be three feet high and eight feet across. At the bottom of this pile is a series of tunnels leading to a nest of soft plant fibers. The pack rat spends its day in the soft nest, somewhat insulated from an exterior air temperature that may be 110°F (43°C), with a ground surface temperature of 160°F (71°C).

Any small mammals dig burrows in the desert soil. The burrow environment is much more moderate than is the surface temperature, which may have an annual fluctuation of between 15°F (9.5°C) and 160°F (71°C). Many desert rodents spend the entire day within the mild environment of a burrow. (A Merriam's kangaroo rat, for instance, will venture to the desert surface for less than one hour each night!) White-tailed antelope squirrels are diurnal rodents that forage for brief periods on the hot daytime desert surface. As they look for seeds, fruits, and insects, their chipmunk-sized bodies heat up, even though their bushy tails hang like parasols over their backs. Above ground, the squirrels may often be observed pressing their bellies, with legs spread, against the cool soil or even tile of suburban patios-in shady spots, allowing, it is presumed, their body heat to be conducted to the cool earth or tile. It has been speculated that the squirrels use the cooler earth in their burrows in a similar fashion when they retreat to them in on hot days.

Speculations made decades ago regarding the behavior of desert rodents in their burrows, and the temperature fluctuations of the rodents and their burrows during the heat of desert summers, have taken on a life of their own as "facts." So have generalizations about temperatures in burrows and pack rat nests that were based on very limited measurements at elevations and conditions far different from those of our
desert extremes. The truth is, we have much to learn about these animals' temperature tolerances and their strategies to avoid overheating. Ongoing and future research assisted by modern technology will, it is hoped, provide us with more complete answers.

Large mammals do not burrow to escape the desert heat. The kit fox, however, is the exception. Unlike any other North American canid, the kit fox uses burrows year round. Burrows help it thrive in hot, dry desert valleys—an environment that is too challenging for other canids. Other large mammals, such as bighorn sheep and mule deer, seek shady spots during the day and remain inactive. Large body size actually has its advantages in the hot desert environment: a large body heats up more slowly than a small body. This phenomenon is called thermal inertia. It may buy enough time to get through a blistering summer day.

**Heat Conduction and Radiation**

Birds or mammals can conduct heat from their bodies to the environment by decreasing the insulating value of feathers or fur. On a hot day, a curve-billed thrasher sleek its feathers which creates a thinner insulating layer. Coyotes lose their thick winter coats in late spring; their early summer coats are relatively thin. A bighorn sheep also sheds its winter coat in the spring—but it sheds it in stages. During the heat of June, the belly and shaded parts of the legs are shed first, providing an area from which to lose body heat; the back, however, remains covered with thick woolly fur that insulates and shades the bighorn sheep from the hot overhead sun.

Birds have some advantages over mammals in dealing with heat. The normal body temperature of birds is generally higher than that of mammals. This higher body temperature means that a Gambel's quail, for instance, with a body temperature of 107°F (42°C), can continue to conduct heat to the air until the ambient temperature reaches 107°F. (A coyote, by comparison, has a body temperature of 102°F.) Also, by dilating the blood vessels going to its bare scaly legs, a bird can dump excess body heat to the environment. A bird's leg temperature may increase 15°F (9.5°C) after its blood vessels dilate. Thus, a hot bird sleeks its feathers and stands tall to expose its legs to the air. Mammals too have "radiators." The long ears of a jackrabbit can transfer excess heat to the air through dilation of the blood vessels to the ear. This works best when the air temperature is below the jackrabbit's normal body temperature (104°F/40°C), or after the jackrabbit has been active.

**Evaporative Cooling**

The primary method for cooling down a hot bird or mammal is through evaporative cooling. As water evaporates from a surface, it cools that surface. When a coyote pants, it rhythmically moves air over the moist surfaces of the mouth, throat, and tongue. Water is evaporated and these surfaces are cooled. Abundant dilated blood vessels are near these surfaces and are cooled by them. The resulting cooled blood is then circulated throughout the body. A hot owl will flap the loose skin under its throat to move air over its mouth cavity. This is called gular fluttering and achieves the same result as panting. Panting and gular fluttering are energy efficient movements that produce very little heat themselves.

Brains are very sensitive to heat. In sheep, and in members or the dog and cat families, evaporative cooling of the nasal passages results in the cooling of a special network of blood vessels to the brain. The brain of an exercising dog, for instance, is cooler than the rest of its body.

Vultures use evaporative cooling in an interesting way. A vulture urinates on its legs if the daytime temperatures are over 70°F (21°C). The urine will evaporate, cooling the legs and drawing more heat from the body of the hot vulture. This is why, when the daytime temperatures are consistently about 70°F, a vulture's legs are white, but when the temperatures are consistently lower than 70°F, a black vulture's legs are gray and a turkey vulture's legs are red.
Water Income and Water Expense

Birds and mammals have a great need for water. Water serves as the basic transport medium for nutrients, and it is the medium for dilution and removal of body wastes. Water functions in most chemical reactions of the living process, and as we have seen, water is the body's primary coolant.

The water-budget balancing act of desert animals has been compared to balancing a bank account: there is water income and water expense. Not surprisingly, it is always a tight budget for desert animals. Stored water is generally limited to what can be placed in the gut or crop. Debts are not tolerated. A 10 to 15 percent loss in body weight due to water loss can impair an animal's ability to recover; a 20 percent loss often means death. Water loss can happen quickly on a hot day in the desert, one to two liters per hour in humans.

What are the sources of water income and water expense?

Water income can come from three sources:

- Free water (for example, a bighorn drinks at a water hole)
- Water in food for example, a Phainopepla eats a juicy mistletoe berry)
- Oxidation water (the water produced by all animals when they metabolize food)

Water expenses can come from:

- Evaporative cooling
- Dilution and excretion of toxic body wastes
- Feces
- Eggs or milk

Some rodents, such as pocket mice and kangaroo rats, are independent of any free water - or even of moist food. The kangaroo rat is probably the best known of these. It eats primarily dry, high carbohydrate seeds; one gram of grass seed produces one-half gram of oxidation water. Seeds with much fat or high protein content are avoided: the former produce too much heat that may have to be lost through evaporative cooling; the latter require too much water for diluting waste products. A kangaroo rat can live on water produced when food is metabolized, but that is only part of its arsenal of strategies for desert survival. Additional water is available from dry seeds which, when stored in its burrow, absorb as much as 30 percent of their weight in water from the higher humidity in the burrow. The evaporative loss from a kangaroo rat is low, as the animal has no sweat glands and little water is passively lost through its skin. Respiratory water loss is reduced by a nasal cooling system that extracts water from air as it passes through the nasal chambers as it is exhaled - a cooling system now known to be shared with other rodents and most other mammals. A kangaroo rat can produce urine twice as concentrated as sea water and feces five times drier than a lab rat's droppings. It conserves moisture further by being nocturnal. Finally, a kangaroo rat typically breeds only when green vegetation or insects are available to supplement its water balance.

Other rodents that do not have regular access to free water consume juicy animals and succulent plants and their fruits. Pack rats and cactus mice are good examples this feeding strategy. During June, the driest month of the year, pack rats can survive on cholla and prickly pear; cactus mice can survive on cactus fruit and insects. There are many other animals besides rodents that get most of their water from food. Elf owls survive on katydids and scorpions. Pronghorns can survive on the water in cholla fruits. Kit foxes can satisfy their water needs with the water in their diet of kangaroo rats, mice, and rabbits, along with small amounts of vegetable material. Other desert dwellers, such as coyotes, mule deer and bighorn sheep, require periodic free water. In fact their home ranges revolve around water holes. Such animals, including we humans, are found only where free water exists, or where it can be transported.
Humans In a Hot, Arid Environment

Humans are physiologically very good at keeping cool, but rather poor at conserving water. Sweating is the primary method of cooling the body; the evaporation of this sweat from all over the body cools the naked skin. During a really hot day in the desert, however, a human will lose as much as 12 liters (a little over 3 gallons) of water through sweat.

Humans have a special mechanism for cooling their big brain: The blood cooled by evaporation of sweat on the face and head penetrate the skull through tiny emissary veins, thus delivering freshly-cooled blood to the brain. This cranial radiator is unique among primates.

Humans' upright, two-legged stance also confers some advantages for keeping cool. When the sun is directly overhead, only the head and shoulders are in full sunlight—a four-legged animal has its entire back, shoulders and head exposed to the sun. Humans therefore gain much less radiant heat than four-legged animals. Also, by standing upright, most of the body is raised above the hot desert floor; this means that humans' rate of heat gain from the desert surface is much less than that of quadrupeds. Being upright also exposes more of the body to cool air currents, and thus body heat can be lost by convection.

Nakedness is also an advantage. Without insulating fur, heat can be lost more easily through convection, and sweat can be more easily evaporated. And that patch of thick hair on top of our heads is more than mere decoration—it shades the head and its heat-sensitive brain from the sun.

Unlike other desert mammals, humans have come up with many cultural and technological adaptations to the desert heat and aridity. Picture yourself on a typical summer day in the Sonoran Desert. What techniques and devices are you using to keep cool and hydrated?
Culture and the Environment
The Sonoran Desert Region covers a geographic area of approximately 100,000 square miles of the southwestern U.S. and northwest Mexico. Its boundaries are defined by the plants, animals, and topography distinct to the region. It is a land of extreme temperatures, high evaporation, low rainfall, and little available water. It is topographically diverse, spanning from sea level deserts along the Gulf of California to higher elevation grasslands and “sky island” mountains which reach up to 9,000 feet in elevation. These factors make it one of the most biologically diverse desert regions in the world.

People have lived here for thousands of years, developing knowledge of the region’s ecology to survive in a sometimes-harsh environment. Native peoples have been technological innovators, constantly observing and experimenting with materials to make life easier. Through observation of the natural the world, native peoples have developed knowledge of the relationships and interactions between living things and their environment to improve their own quality of life and chances for survival.

**Ethnoecology and Ethnobotany**

Ethnoecology is the modern study of how cultures such as native groups manage the natural and modified ecosystems they inhabit to meet their needs for survival. It is an ecological approach to understanding traditional knowledge of land, plants, and animals in a local environment. Ethnobotany is the study of how people use plants. The Sonoran Supermarket Desert Discovery Program and Sonoran Supermarket Lending Kits focus on the plant materials available to native peoples in the region because in their diversity and abundance, plants provide the majority of the materials needed for human survival, including food, medicine, shelter, tools, clothing, and more. Of the over 2500 species of plants in the Sonoran Desert, it is estimated that nearly 30% (or 750 species) have been documented as being used in some way by the various desert cultures.
People of the Sonoran Desert Region

Numerous groups of native people inhabit the Southwestern U. S. and northwestern Mexico. Several are indigenous to the Sonoran Desert, including the Tohono O’odham, Hia-Ced O’odham, Akimel O’odham, Pima, Yaqui (Yoeme), Cocopa, Yuma, and Seri. The neighboring highlands of the Sierra Madre in Sonora, Mexico, are also home to the Opata, Warihio, Jova, Mayo, and Lower Pimans.

The Sonoran Supermarket Desert Discovery Program and Sonoran Supermarket Lending Kits focus primarily on three groups of native peoples: the Tohono O’odham, Yaqui (Yoeme) and Seri. Each group traditionally utilized planting, harvesting, and ceremonial cycles based on the seasons and available resources found in their particular region. Although species vary from location to location, many of the plant genera and uses are similar. Previously, many of these people led a somewhat nomadic lifestyle, migrating with the seasons, or moving because of conflict between different cultural groups in their homelands. Today their lands have been restricted to specific areas dictated by U.S. or Mexican federal decree.

**Tohono O’odham**

For thousands of years, the traditional O’odham homelands encompassed a vast area of the Sonoran Desert region, from northern Sonora and west to the Gulf of California, north to central Arizona near present-day Phoenix, and east to the San Pedro River basin. In historic times, these lands and their residents have had many designations imposed upon them by foreign governments including Spain, Mexico, and the United States. Today O’odham peoples are federally recognized in the United States as four geographically and politically distinct tribes: The Tohono O’odham Nation, the Gila River Indian Community, the Ak-Chin Indian Community, and the Salt River (Pima Maricopa) Indian Community. A fifth, the Hia-C’ed O’odham, are not federally recognized, but reside throughout southwestern Arizona. All groups speak various dialects of the O’odham language, derived from the Uto-Aztecan language group. The name Tohono O’odham (Toe-HO-no AH-tum) means “Desert People.” The tribe was formerly known as the Papago, which is a Spanish corruption of a Piman term for “tepary bean eater”.

The Tohono O’odham Nation is the second largest reservation in the U.S., covering 2.8 million acres or 4,460 square miles of Sonoran Desert in four non-contiguous parcels. In Sonora, approximately nine O’odham communities are found just across the U.S/Mexico border. Formerly, residents of these communities crossed the border freely to utilize health care and other services available to tribe members north of the border, but today, tighter U.S. immigration policies have made this more difficult, resulting in division between these communities.

Oral tradition indicates that the Tohono O’odham are likely descendants of the early farmers and later Hohokam people who inhabited the Tucson area from around 500 A.D. until around 1450 A.D. Historic records of the Tohono O’odham in the region began with the arrival of the Spanish around 1690. In 1691, Father Kino made contact with the Tohono O’odham living at Bac and Chuk Shon. In 1700 he established the Mission San Xavier del Bac and introduced Christianity, wheat, livestock, fruit, and metal tools to the region. The San Xavier Reservation was established in 1874, and the main Tohono O’odham reservation was established in 1917.
Today the Tohono O’odham tribe includes approximately 28,000 members. The tribal government runs health care, education, and other services. The Tohono O’odham language is still spoken and taught in schools, but fluency has declined markedly with younger generations. Entities such as the Tohono O’odham Cultural Center and Museum, Tohono O’odham Community College, and Tohono O’odham Community Action (TOCA) are making great efforts to keep the traditions of the people alive and pertinent to tribal life today.

**Yaqui (Yoeme)**

The Yaqui homeland is centered along the rich floodplain of the Yaqui River Valley in Sonora, Mexico, where they farmed and fished. By 552 AD, Yaqui family groups ranged and settled throughout the Sonoran Desert region as far north as the Gila River. The Yaqui traded native foods, furs, shells, salt and other items with tribes including the Shoshone, Comanche, Pueblos, Pimas, Aztecs, and Toltecs. Their oral traditions prophesied disunity and invasion by foreign peoples, and by pre-Columbian times they were organized into autonomous but unified military and cultural groups, prepared to defend their homeland along the Yaqui River.

In 1533, the Yaquis encountered the first white men in their region, a Spanish military expedition, which heralded in a 400 year period of conflict and struggle against successive waves of Spanish and Mexican settlers seeking to subjugate them and take their lands. Between 1608 and 1610, the Spanish attacked violently and repeatedly, but the Yaquis successfully raised an army of 7,000 to defeat them. In an effort to secure peace, the Yaquis asked the Jesuit missionaries to establish churches, and most of the 60,000 Yaquis settled in the eight sacred “pueblos” or towns where these churches were established.

Peace was elusive, however. The Yaquis continued to resist subjugation, despite massacres, deportation, and disease diminishing their population. Many Yaquis left Sonora to join family groups in Arizona living along the Santa Cruz and Gila Rivers in communities such as Old Pascua and Barrio Libre in Tucson, Yoem Pueblo in Marana, and Guadalupe near Tempe. Today, the Yaqui have lands in both Mexico and the U.S. formally recognized by both governments. In 1939, the Yaqui of Sonora received official recognition and title to their land, yet the loss of culture continued as large dams along the Yaqui River forced Yaqui farmers to buy water, further diminishing their self-sufficiency. Today an estimated 32,000 Yaquis live in the region.

In 1964, the Pascua Yaqui Association received 200 acres southwest of Tucson where New Pascua Pueblo was built. In 1978, New Pascua received formal recognition as a U.S. Indian Tribe. The older Yaqui communities are not formally recognized by the U.S. Bureau of Indian Affairs, but they receive help from the tribal government of New Pascua. About 6,000 Yaquis live in the U.S. today. Yaqui cultural traditions, with their unique blend of indigenous and Christian beliefs, flourish in southern Arizona. Yaqui Easter Ceremonies are open to the public at Old Pascua and include a week of traditional music and masked dancers depicting events of Holy Week. Central to the Easter observances is the Deer Dancer, a highly respected and important symbol of ancient Yaqui cultural and spiritual belief.
The Seris, or Comcáac, as they call themselves, live along the central Gulf of California coast of Sonora, Mexico, across from Tiburón Island. They are a unique cultural group of hunter-gatherers and seafarers who survive in some of the harshest conditions within the Sonoran Desert region, where annual rainfall rarely exceeds two inches. Drinking water here is a scarce commodity, limiting the size of communities to extended family groups. These groups were small and nomadic – they migrated over large areas and dwelled in temporary camps to find resources to survive. At first contact with the Spanish with Coronado’s expedition in the 16th century, the population of Seri groups was probably around 5,000 people. Like other indigenous groups, their territory and numbers shrunk as a result of persecution and disease. In the 1930’s only about 300 Seris remained, most of them concentrated on Tiburón Island. The straight that separates the island from the mainland is one of the most dangerous in the world, but the Seri navigated it expertly on balsa rafts made of carrizo or reedgrass (Phragmites australis) lashed together with mesquite root twine.

By the 1960’s the Seri returned mostly to the mainland, participating in the fishing economy of the region. They also became known for their ironwood carvings and basketry. Today the population is close to 1,000 people living in the two villages of Punta Chueca and El Desemboque north of Kino Bay, Sonora.

**Tucson: A Long History of Settlement**

Tucson’s name is derived from the Tohono O’odham word Chuk Shon, meaning “black base,” which refers to the foot of Sentinel Peak or “A” Mountain. At this spot, the mountain’s bedrock pushed groundwater along the Santa Cruz River basin to the surface, providing life-giving perennial flow until overpumping in the last century depleted it completely. What we view today as a dry, channelized ditch that only flows after rain storms was once a lush riparian area where native communities lived, subsisting off wild foods and using the river’s water to cultivate corn, beans, squash, and possibly cotton. Recent archaeological excavations near A Mountain have revealed that Tucson has been home to native people for at least 4,000 years, making it one of the oldest continuously inhabited settlements in the U.S.

Beyond the permanent water in the Santa Cruz River, other factors also made this setting ideal for survival. Mild winter temperatures and two distinct rainy seasons provide for a nearly year-round growing season with two distinct periods of plant growth. Gentle winter rains allow for the harvest of wild greens and herbs from February through April. They also provide moisture for perennial plants like legume trees and cacti which set fruit and seed in late spring or early summer, awaiting germination with summer monsoon storms. Wild foods, supplemented with crops of squash, beans, and corn, are available throughout an annual succession of harvests; one food often ripens just as another becomes scarce. For example, cholla buds are collected in early spring, saguaro cactus fruits in foressummer, and prickly pear cactus fruits in mid-summer. Mesquite pods are ready to harvest in late summer and early fall as cactus fruits become scarce. Food storage was an important provision against starvation during the lean times between harvests. Ethnobotanical knowledge of when and where shoots appear, fruits ripen, and roots or bulbs are ready for harvest, as well as how to store and preserve them, requires an intimate awareness of the Sonoran Desert environment.

It is important to note that ethnobotany is the study of all people's uses of plants. "Newcomers" to the Sonoran Desert, settlers who arrived beginning with the Spanish in the late 1600’s, have also made use of the native plants of the desert. For example, Hispanic “curanderos” used native plants for medicine or ceremony, learning from native groups and from their own experimentation.
Native knowledge is still alive in our region and still useful, even vital, today. The Tohono O’odham, for example, suffer some of the highest rates of diabetes in the U.S., due largely to the incorporation of processed carbohydrates and sugary foods into their diet. Many of the native foods they traditionally consumed, however, have been proven to be highly effective in managing blood sugar. Groups such as Tohono O’odham Community Action (TOCA) are calling for a return to the use of these native foods to keep their people healthy. Additionally, these foods grow in many Tucson back yards as landscape plants and can provide a fun and healthful way to forge a deeper sense of place that is connected to the long history of native plant use in this region. Organizations such as the Arizona-Sonora Desert Museum, Tucson Botanical Garden, Native Seeds/SEARCH, the Community Food Bank, Desert Gatherers, Santa Cruz Valley Heritage Alliance, and Pima County Natural Resources, Parks and Recreation offer a wide variety of learning opportunities within our community.
In 1922, Aldo Leopold and his brother canoed through the delta of the Colorado River. They hunted quail and geese, watched bobcats swat mullet from driftwood logs, and dreamed of el tigre (jaguar), whose "personality pervaded the wilderness", even though they never saw any of the big cats. "For all we could tell, the Delta had lain forgotten since Hernando de Alarcón landed there in 1540," Leopold mused. "When we camped on the estuary which is said to have harbored his ships, we had not for weeks seen a man or a cow, an axe-cut or a fence" (Leopold 1949, 141). "On the map the Delta was bisected by the river," the famed conservationist goes on to say, "but in fact the river was nowhere and everywhere, for he could not decide which of a hundred green lagoons offered the most pleasant and least speedy path to the Gulf. So he traveled them all and so did we. He divided and rejoined, he twisted and turned, he meandered in awesome jungles, he all but ran in circles, he dallied with lovely groves, he got lost and was glad of it, and so were we. For the last word in procrastination, go travel with a river reluctant to lose his freedom in the sea."

By the time Leopold wrote those words in the 1940s, he knew he was writing an elegy, not a paean. The river mighty enough to support a jungle in the desert had already lost its freedom, not to the Gulf of California into which it emptied, but to California farmers and the City of Los Angeles. Beginning in the 1890s, Anglo-American promoters and government engineers strove to break the Colorado to the new Western order. Their first attempts nearly triggered a geological catastrophe, when floods in 1905 sent the Colorado roiling down a canal with no headgate and turned the Salton Sink into the Salton Sea. In 1936, however, a white wall of more than three million cubic yards of concrete rising 726 feet against black rock halted the river in its tracks. Erected to prevent floods and to provide hydroelectric power, Hoover Dam turned the Colorado into a tame ditch for the last 300 miles of its course to the sea. The Colorado and its tributaries, along with the other major rivers that brought water to the Sonoran Desert, such as the Yaqui and the Mayo, became ghosts of the past, victims of the twentieth century, carcasses of sand whose lifeblood had been diverted into cotton fields, copper mines, and vast, sprawling cities.

The Native Americans

Leopold foresaw the transformation and never revisited the delta. "I am told the green lagoons now raise cantaloupes. If so, they should not lack flavor," he wrote. "Man always kills the thing he loves, and so we the pioneers have killed our wilderness" (Leopold 1949, 148).

The passion of those words rang with recrimination. But they also reflected a deeply American romanticism as well. Leopold felt that he was witnessing the death of wilderness in the Southwest. Like most Anglo-American newcomers, however, he underestimated the impact that native peoples had already visited upon the Southwestern landscape. Much of the Sonoran Desert, after all, had been homeland to American Indians for at least 12,000 years. Their transformations were more subtle, and in most cases more benign, but human groups have shaped the flora and fauna of the Sonoran Desert, including the Colorado delta, for millenia.

Geoscientist Paul Martin believes that Paleoindians armed with stone-tipped spears overhunted the great Pleistocene mammals of North America and helped drive them to extinction. His Pleistocene overkill theory is controversial, but prehistoric Indian societies clearly had an impact upon local animal populations.
Analyzing animal bones from hundreds of Hohokam sites in central and southern Arizona, zooarchaeologist Christine Szuter traces a decline in artiodactyls (deer, bighorn sheep, and pronghorn antelope) and an increase in rodents and in lagomorphs (cottontails and jackrabbits) as Hohokam settlements grew larger and more sedentary. In other words, the longer Hohokam lived in an area, the more they hunted out the big game and relied upon rabbits and rodents for animal protein. And as they cleared desert vegetation for firewood and fields, they also harvested more jack rabbits, which fled predation by running across flats, and fewer cottontails, whose instincts told them to dash for cover that was no longer there.

The Sonoran Desert's prehistoric Hohokam were sophisticated desert farmers who built the largest system of irrigation canals in pre-Colombian North America. This section of canal was exposed during the 1964-1965 excavations at Snaketown, located northwest of the present-day town of Sacaton, Arizona.

The Hohokam were sophisticated desert farmers who built ballcourts, platform mounds, and the largest system of irrigation canals in pre-Columbian North America. But even hunters, gatherers, and fisherfolk manipulated the distribution of plants and animals. The Comcáac, or Seri Indians, live on the coast of Sonora in one of the driest landscapes on the continent. Seris never cultivated domestic plants or raised domestic animals except dogs, but they did carry certain species of wild plants and animals with them as they moved across the desert and sea. According to ethnobiologist Gary Nabhan and his colleagues at the Arizona-Sonora Desert Museum, their sojourns expanded the range of at least five of the forty-nine species of terrestrial reptiles in Seri territory beyond areas where they naturally occurred.

A case in point is the story of the piebald chuckwallas of Isla Alcatraz in Bahía Kino. These large lizards exhibit traits from three different species—Sauromalus varius, from San Esteban Island, S. ater from the Sonoran mainland, and S. hispidus from the western midriff islands. During the earlier part of this century, when Asian demand for the swim bladders of totoabas (Totoaba macdonaldi, the largest member of the croaker family) triggered a fishing boom in the Gulf of California, Seri fishermen released chuckwallas and iguanas as survival foods on islands like Alcatraz. On Alcatraz, at least, the chuckwallas interbred to create a larger, meatier reptile. These hybrids are the result of cultural, not natural, processes of biogeographic distribution. Piebald chuckwallas may not rival Hoover Dam, but they do represent human-induced changes in the Sonoran Desert.
Contrary to romantics like ecologist Stanwyn Shetler, pre-Columbian America was not a pristine natural kingdom where the native people were transparent in the landscape, living as natural elements of the ecosphere (Shetler 1991, 226).

The most intensive way pre-Columbian Native Americans transformed their environments was through agriculture. Archaeologists are finding evidence that so-called "Archaic" peoples were growing maize (corn) at least 3000 years ago in well-watered areas like the Tucson Basin. Then came pinto and tepary beans, gourds, squash, cotton, and a host of other plants including amaranth and devil's claw. The Cocopas cultivated Sonoran panic grass in muddy sloughs along the Colorado delta. They, like the Quechan, Mojaves, Yoemem (Yaquis), and Yoremem (Mayos), practiced flood-plain-recession agriculture, planting their crops as floodwaters receded. The Hohokam and their successors, the Akimel O'odham (Upper Pimas), on the other hand, dug canals to divert water from Sonoran Desert rivers onto their fields. Hohokam canal systems along the Salt and Gila rivers snaked across the desert floor for nearly 100 miles (160 km) in the Florence area and for 125 to 315 miles (200 - 500 km) in the Phoenix Basin. Hohokam farmers did not use all sections of these canal systems at any one time. Nonetheless, they still irrigated between 30,000 and 60,000 acres (12,000 - 24,000 ha) in the Phoenix Basin alone.

Hohokam farmers also constructed ditches and brush weirs along alluvial fans to divert runoff onto their fields after summer rains. This form of agriculture, sometimes called ak-chin among Tohono O’odham in southern Arizona and temporal among mestizos (people of mixed Hispanic and Indian ancestry) in rural Sonora, is still being practiced today. North of Tucson, however, the Hohokam developed an enormously labor-intensive type of agriculture that did not survive into the historic period. Archaeologists Paul and Suzanne Fish and their colleagues at the Arizona State Museum discovered more than 42,000 rock piles in association with contour terraces and checkdams on the western slopes of the Tortilita Mountains. They also found huge roasting pits containing charred fragments of agave. The rock piles protected young agave plants from predation by rodents and conserved moisture by reducing evaporation around their bases. During the twelfth and thirteenth centuries, more than 100,000 agaves may have been simultaneously growing in these rock pile fields.

The Arrival of the Europeans

The Marana community that cultivated those agaves abandoned the northern Tucson Basin in the mid-fourteenth century. About the same time, in the winter of 1358-59 A.D., a massive flood roared down the Salt and Verde rivers, washing out canals and washing away fields in the Salt River Valley. The flood was followed by two decades of drought and more floods in the early 1380s. Hohokam communities along the Salt may never have recovered from those climatic calamities.

Other Hohokam communities along the Gila River survived into the fifteenth century. By the time the first Europeans settled in the region in the late 1600s, however, Hohokam civilization had collapsed. Some archaeologists speculate that centuries of highly mineralized irrigation water may have saturated Hohokam fields with salts until they could no longer produce crops. Others argue that increasing political conflict may have caused Hohokam society to implode. Pima creation narratives describe the ancestors of the O’odham emerging from beneath the earth to destroy "great houses" ruled by powerful priest-chiefs along the Gila River. The conquest begins with Casa Grande and ends with Pueblo Grande, governed by the priest-chief Yellow Buzzard. Many archaeologists believe that the O’odham are descendants of the Hohokam. O’odham creation narratives, in contrast, portray themselves as conquerors.
Regardless of how or why Hohokam civilization disintegrated, the peoples of the northern Sonoran Desert were living much simpler lives when Jesuit missionary Eusebio Francisco Kino and his companions encountered them. We know much less about the pre-Columbian peoples of Sonora because so little archaeological research has been done south of the international border. At the time of initial European contact in the sixteen century, large populations of Cahita-speakers—the ancestors of the Mayos and Yaquis—lived along the Mayo and lower Yaqui rivers. Opatas and Eudeves dominated the Sonora River valley and the upper Yaqui and its tributaries. So-called Pimas Bajos, or Lower Pimas, occupied a wide crescent between the Opatas and the Yaquis. All of these peoples spoke Uto-Aztecan languages and relied upon agriculture for at least part of their diet.

Once the Europeans arrived, however, one of the greatest ecological revolutions in the history of the world transformed both lives and landscapes. Biological historian Alfred Crosby calls this revolution the Columbian Exchange—that flow of genes, microbes, plants, and animals between the "Old World" of Eurasia and Africa and the "New World" of the Americas. The first revolutionary wave may even have preceded the Europeans themselves: Indians infected with Eurasian diseases like measles, influenza, and smallpox may have unsuspectingly unleashed contagions as they traveled up ancient trade routes from central Mexico. Some archaeologists and ethnohistorians even contend that these diseases may have contributed to the demise of Hohokam civilization itself.

We may never know exactly when the first epidemic spread death and devastation among the Indians of the Sonoran Desert. What we do know is this: thousands of Yaquis and Mayos were perishing when the first Jesuit missionaries ventured into Cahita territory in the early 1600s. The pattern repeated itself again and again at five- to eight-year intervals as Spanish settlers pushed northward into the Opatería and the Pimería Alta. Epidemiologically virgin populations had no genetic resistance or cultural mechanisms to resist the microbial onslaught. Like native peoples all over the Americas, the number of Indians in the Sonoran Desert declined by as much as ninety-five percent over the next two centuries.

For the Indians who endured, however, the Europeans brought new crops, new tools, and new animals that revolutionized their economies and their means of transportation. Winter wheat filled an empty niche in their agricultural cycle because it could be planted in November, when frosts at higher elevations in the Sonoran Desert would have withered corn, beans, or squash. Mules and oxen enabled them to cultivate their fields with wooden or iron plows, intensifying their reliance upon agriculture. Cattle, sheep, and goats allowed them to convert non-edible forbs and grasses into beef, mutton, cheese, milk, leather, and tallow. Horses expanded their ranges and shrank distances. A Euro-American agropastoralist economy—irrigation agriculture along the floodplain, animal husbandry in the uplands—supplemented, complemented, and slowly replaced digging-stick agriculture and wild food gathering.

Cattle, horses, and mules had other consequences as well. In November 1697, Kino and his frequent traveling companion Juan Mateo Manje visited Sobaipuri Pimas along the Babocomari River in southeastern Arizona. They found O'odham performing a circular dance around a tall pole dangling nine scalps. Sixteen Janos and Jocome raiders had tried to run off their small herd of livestock—livestock they had received from the Jesuit missionary. Kino's gifts of cattle and horses had made O'odham along the San Pedro River targets of Jocome, Janos, and Apache raiding. Because of those raids, O'odham along the San Pedro eventually had to retreat to the Santa Cruz River Valley, while Pimas along the Gila River organized themselves into larger villages with a standing army of 1000 men nearly one-fourth their total population. The introduction of Old World livestock into the Sonoran Desert triggered a pattern of raiding and retaliation between O'odham and Apaches that lasted for 200 years.
Spaniards and Mexicans

That same pattern made mission Indians and Hispanic frontiersmen allies of one another, as their guerrilla war fare with the Apaches intensified. Spaniards and their mixed-blood descendants were a minority in the Sonoran Desert until the mid- to late-eighteenth century. That meant that even though they exploited Indian labor and encroached upon Indian land, they also depended upon Yaquis, Mayos, Opatas, and Pimas for their very existence on a dangerous frontier.

Some groups, such as the Yaquis, kept Hispanic colonists from penetrating their territory until the late 1800s. Among the Opatas and Lower Pimas, on the other hand, Spaniards, mestizos (Spanish-Indian), coyotes (mestizo and Indian), and mulattos settled in or near mission communities despite the protests of the missionaries. Mestizaje—racial mixture—weakened ethnic boundaries, as competition for arable land and irrigation water increased in Sonoran Desert river valleys. Those river valleys—the Sonora, the Bavispe, the Santa Cruz—became riparian oases of Hispanic civilization in the desert.

Stock raising was the most land-extensive Euro-American transformation of the Sonoran Desert. Cattle, horses, goats, and sheep searched for forage from river floodplains to mountain crests. In more settled areas like central Sonora, overgrazing became endemic during the Spanish colonial period. The presidio (military garrison) and town of Pitic (modern Hermosillo) alone ran 5000 head of cattle, 3422 sheep, 435 goats, 2138 horses, and 367 mules in 1804 (Radding 1997, 218). But Apache hostilities prevented ranchers from expanding beyond the Santa Cruz Valley in southern Arizona. During the 1820s and 1830s, the Mexican government issued nine land grants in southern Arizona. All were largely abandoned by the 1840s. Hispanic stock raising never was sustained enough to have a widespread impact upon the southern Arizona landscape except along the Santa Cruz.

Apache attacks also checked the northward expansion of mining, the most land-intensive industry in Hispanic Sonora. In less vulnerable areas, however, mining lured thousands of Indians and non-Indians alike from strike to strike. There were two types of mining communities in the region. The discovery of silver in 1683 south of the Río Mayo led to the development of Alamos, a city of wealth and social stratification based upon the enormous capital investment required to extract and process silver ore. Cieneguilla in northwestern Sonora, on the other hand, was a desert boom town where gambucinos (prospectors) dry-winnowed alluvial deposits for particles of gold. Vein-mining operations like that of Alamos depended upon large, stable labor forces organized into hierarchies of occupations. Placers like Cieneguilla attracted restless, mobile congregations of Spaniards, mestizos, Yaquis, Opatas, and Pimas, most of whom worked for themselves. No other economic activity so thoroughly rearranged social relationships on New Spain's and then Mexico's northern frontier.

The same could be said about mining's impact upon local and regional environments. Most placers faded into the desert, however, while silver-mining districts like Alamos or San Juan Bautista in the Río Moctezuma Valley continued to generate voracious demands for charcoal, timber, firewood, tallow, salt, and mercury for decades and even centuries. To supply these mining districts, stock ranches also proliferated, creating what geographer Robert West (1949) calls the "ranch-mine settlement complex". Complex webs of economic relationships linked far-flung mining communities with merchant and imperial capital in Mexico City and Madrid. Meanwhile, hillsides were denuded, streams diverted, water tables polluted, and vegetation communities irrevocably changed.
Anglo-Americans

Those social and ecological patterns replicated themselves after the United States wrested away more than half of Mexico's national territory during the Mexican War of 1845-1848. Gold and silver lured Anglo-Americans and Europeans to the northern Sonoran Desert—first along the Colorado River as placer booms like the one at La Paz flared and faded, then in the mountains along the Hassayampa River, where the town of Wickenburg sprang up to reduce and mill silver ore. Precious metals were the only commodities worth the enormous transportation costs on such an isolated and dangerous frontier.

And Arizona was a frontier for the first three decades of its existence as a part of the United States. From the arrival of the Europeans until the 1880s, the Arizona-Sonora borderlands were a frontier in the most basic sense of the term; contested ground where no single tribe, empire, or nation held uncontested sway. Because Apaches, Yavapais, and River Yumans resisted European and Euro-American conquest so successfully for two centuries, Euro-American impact upon the desert environment was intermittent rather than sustained.

That all changed in the 1880s, when the Era of Extraction began. In 1877, the Southern Pacific Railroad reached Fort Yuma on the Colorado River. Three years later, after its largely Chinese crews had laid tracks across some of the hottest, driest terrain in North America, the railroad steamed into Tucson. At the gala celebration on March 20, 1880, Mexican intellectual Carlos Velasco raised a toast to the "irresistible torrent of civilization and prosperity" that would follow the steel rails. Six years later, when Geronimo surrendered to General Nelson Miles for the final time, the frontier came to an end. Suddenly, Arizona and Sonora were safe for global capital, which poured in from the eastern United States, California, and the British Isles, as the Southern Pacific and other railways extended their arteries of commerce across deserts and mountains. Both Arizona and Sonora became extractive colonies of the industrial world, their natural resources ripped from the ground and shipped somewhere else for finishing, processing, and consuming. In Arizona, this was the era of the "Three C's", when cattle, copper, and cotton dominated the economy.

The first major extractive industry to explode across the landscape was stock raising. In 1870, there were perhaps 38,000 head of cattle in the Arizona Territory. By the early 1890s, there were about 1,500,000 head of cattle and more than a million sheep, many of which had been shipped into the territory by rail. Stock raising expanded south of the border as well, as investors like Colonel William Henry Greene put together vast ranches on the grasslands of northern Sonora. Pascual Encinas even drove his cattle onto the coastal plains west of Hermosillo, establishing his famous Costa Rica Ranch at Siete Cerros on the edge of Seri territory. Encinas tried to train the Seris as laborers and offered them religious instruction. But as more ranchers moved onto their desert hunting and gathering grounds, the Comcáac responded by killing cattle for food. By the late nineteenth century, the "Encinas War" erupted, pitting cowboys armed with repeating rifles against Seris armed with bows and arrows. The Comcáac were decimated. Sonora's march to the sea began.

The second major extractive industry—copper mining—depended even more heavily upon the railroads. Unlike gold and silver, copper was an industrial rather than a precious metal. The evolution of the industry therefore became the triumph of technological innovation over declining grades of ore. Staggering amounts of earth had to be moved to extract a metal that eventually constituted less than one percent of its ore bodies, and that earth had to be moved from mine to smelter in railroad cars, not in freight wagons or on the backs of mules. In copper districts like Bisbee, where Phelps Dodge Corporation's Copper Queen reigned supreme, thousands of miles of shafts and tunnels burrowed underground. And while most of these early districts were in the uplands fringing the Sonoran Desert, Phelps Dodge and other giants eventually chewed into the desert as well, particularly after open-pit mining became feasible. At Ajo, Mammoth, Twin Buttes, and Silverbell, giant holes begat gargantuan slag heaps, which rose above the desert floor like pyramids erected in honor of the Electrical Age.
Water Control and the Transformation of the Desert

The third major extractive industry—agriculture—led to the ultimate transformation of the Sonoran Desert. For 3000 years, farmers had cultivated their crops along those few stretches of the desert where surface water flowed near arable land. In Sonora, the major agricultural areas were located in the river valleys of the zona serrana, the mountainous central and eastern portions of the state. Generally trending northeast-southwest, successive mountain ranges and river valleys cradled Opata, Eudeve, and Lower Pima communities. During the Spanish colonial period, the serrana attracted Spaniards and their mestizo descendants as well, who raised wheat, fruits, vegetables, and sugar cane along its cottonwood-shaded floodplains.

After Mexico won its independence from Spain in 1821, however, Guaymas became Sonora's most important port of entry, and a strong commercial axis between Guaymas and Hermosillo (formerly Pitic) - the gateway to the serrana - developed. Merchants and military officials cast covetous eyes on the rich coastal floodplains of western and southern Sonora, particularly the Yaqui and Mayo river valleys. The Yaquis fought a bloody war of resistance but by the late nineteenth century, the Hiakim, or Yaqui homeland, had been occupied by the Mexican army. The Sonoran state government under Governor Rafael Izabal then decided to eliminate the Yaquis once and for all by deporting thousands of Yoemem to the Oaxaca Valley or to henequen plantations in the Yucatán. It was cultural genocide in the service of "order and progress".

Speculators soon descended upon the Yaqui Valley with grand plans to irrigate the coastal plains. In 1890, the Mexican government granted Carlos Conant Maldonado 300,000 hectares (one hectare, or ha = 2.47 acres) along the Río Yaqui, 100,000 ha along the Río Mayo, and 100,000 ha along the Río Fuerte in northern Sinaloa in return for surveying the area and building canals along each river. Conant's Sonora and Sinaloa Irrigation Company, incorporated in New Jersey with U.S. capital, soon went bankrupt, but the Richardson Construction Company purchased Conant's grant in 1906. In exchange for selling 400-hectare blocks of land and supplying irrigation water to colonists, most of them from the United States or Europe, the Compania Constructora Richardson, S.A. received exclusive right to sixty-five percent of the Río Yaqui's flow for ninety-nine years.
The Richardson brothers had big plans to build storage dams on the Yaqui to generate electric power and furnish water to a network of canals capable of irrigating 300,000 hectares. The Mexican Revolution and World War I destroyed their enterprise but the dream of transforming the Yaqui Valley into a vast grid of irrigated agribusiness bore fruit in 1952, when the Mexican government completed Alvaro Obregón Dam at Oviachi forty miles away. Along with dams upriver, the Oviachi reservoir controlled flow along the lower Río Yaqui and eventually channeled its water into three major canals that irrigate nearly 600,000 acres in the Yaqui Valley. Ciudad Obregón, a city of more than 500,000 people, arose to service the largest irrigation district in Sonora. Recognizing the Yaqui Valley’s importance, the Rockefeller Foundation established a wheat-breeding station on the outskirts of Obregón under the direction of Dr. Norman Borlaug. This station became one of the hearths of the Green Revolution, that controversial program that dramatically increased wheat production—all of it dependent upon high inputs of chemical fertilizers and pesticides—around the world.

North of the Yaqui Valley, advances in pump technology after World War II allowed other coastal irrigation districts to bulldoze desert plains and convert them into wheat and cotton fields. The largest was the Costa de Hermosillo where, at its height, 887 pump-powered wells regurgitated water onto more than 100,000 hectares. But discharge exceeded recharge by 250 percent. As water tables plummeted and salt water intruded from the Gulf of California, the Mexican government finally stepped in and halved the amount of water that could be pumped. Many fields were abandoned. Other farmers switched from relatively low-value crops like cotton to high-value, high-risk crops like brandy grapes, citrus, garbanzo beans, and vegetables destined for U.S. markets.

Because of these developments, Sonora's demographic, political, and economic center of gravity shifted from the serrana to the coast during the twentieth century. Dam-building and groundwater pumping enabled capital-intensive agricultural districts to plow under great mesquite bosques (forests) west of Hermosillo and desert ironwood plains around Caborca. Those twin pillars of modern water control also allowed older cities like Hermosillo (about 800,000 population) to expand, and entirely new cities like Cuidad Obregón to spring up like an industrial flower south of the dry channel of the Río Yaqui. But whether these flowers are perennial or ephemeral remains to be seen. Hermosillo already experiences severe water shortages during dry seasons and dry years. Groundwater districts like Caborca and the Costa de Hermosillo are contracting painfully as aquifers drop and pumping costs escalate. Even the Yaqui Valley with its huge reservoirs faces an uncertain future as the North American Free Trade Agreement (NAFTA) reshapes Mexican agriculture. Most farmers in the valley now plant wheat in the winter and soybeans in the summer. As subsidies are removed and trade barriers lowered, many question whether Sonoran producers can compete with Canadian and U.S. farmers dry-farming the same crops.

In Arizona, the future of agriculture is held hostage to urban growth. During the early twentieth century, the newly created Reclamation Service (precursor of the U.S. Bureau of Reclamation) erected Roosevelt Dam in 1903 on the Salt River east of Phoenix and turned the Salt River Valley into one of the largest agricultural centers in the Southwest. And when a British embargo on long-staple industrial cotton during World War I triggered Arizona's cotton boom, commercial agriculture spread south across the saltbush and creosote bush flats between Phoenix and Tucson. Arizona became one of the leading cotton producers in the world.

But World War II and the postwar boom thrust Arizona from the Era of Extraction into the Era of Transformation, turning an overwhelmingly rural state into an overwhelmingly urban one. Thousands of acres of citrus and cotton sprouted subdivisions and malls as Phoenix and its satellites sprawled into a metropolis of more than 2,500,000 people by 1995. Metro Tucson approached 750,000. By the time the Central Arizona Project (CAP) - a farmer's dream since the 1920s - reached Maricopa, Pinal, and Pima counties, many farmers could not afford its water. The CAP became one more bargaining chip in the water game, that escalating contest that pitted relentlessly expanding cities against farmers, miners, and Indian nations.
Visions and Nightmares

Water has always been the ultimate limiting factor on human society in the Sonoran Desert. Until the late nineteenth century, people largely relied upon surface flow, adapting to rivers rather than making the rivers adapt to them. This century, however, dams have domesticated all major rivers in the region while pumps have mined groundwater aquifers far beyond recharge. Arizona's 1980 Groundwater Management Act mandates that "safe-yield" (when discharge does not exceed recharge) be reached by the year 2025 in four Active Management Areas which together are home to eighty percent of Arizona's population. Certain areas of the Sonoran Desert may indeed see population growth slowed or halted because they are running out of water.

The twentieth century has seen the transformation of Arizona from an overwhelmingly rural state to an overwhelmingly urban one, as seen in these two photos of Tucson: about 1900 (top) and 1999 (bottom). Both photos taken at the intersection of Scott and Congress.

But other areas like metropolitan Phoenix will spread unchecked as long as they can wrest more water away from farmers and Indian nations. For much of its history as a part of the United States, Arizona has suffered from a bad case of "California envy", battling its more powerful western neighbor for Colorado River water, yet emulating its explosive growth. Unless it consciously decides to restrict growth, however, Arizona will become the southern California of the twenty-first century. Metropolitan Phoenix will embrace five to seven million people. Tucson will reach 1,500,000 and learn to guzzle the CAP water it has twice refused to drink in the 1990s.
Ambos Nogales (two cities of the same name separated by the international boundary) may resemble El Paso-Juarez if free trade and the maquiladora (assembly plant) program keep on luring millions of Mexicans to the border. And since most of Arizona and Sonora's population now live in the Sonoran Desert, the urban assault will only intensify.

Meanwhile the Columbian Exchange continues to rearrange the countryside. Since 1942, the number of non-native plants in Arizona alone has risen from 190 to approximately 330 species. During the 1930s, agents of the Soil Conservation Service promoted a South African grass called Lehmann lovegrass to control erosion. Today it covers more than 400,000 acres of Arizona.

Beginning in the 1960s, Sonoran range scientists introduced another African grass—buffelgrass—to increase forage production. More than one million acres of desert and subtropical thornscrub have now been scraped away to plant this exotic. Ecologist Tony Burgess of Columbia University's Biosphere II calls such proliferation the "Africanization of the Sonoran Desert". Aldo Leopold may have underestimated past peoples' manipulation of the Southwestern landscape. He would have shuddered at how utterly we have transformed the Sonoran Desert since he and his brother drifted along the green lagoons.

References


Additional Reading


A Sense of Our Place in the Sonoran Desert

Following is a selection of books from Desert Stories: A Reader's Guide to the Sonoran Borderlands, an Arizona-Sonora Desert Museum Sense of Place Project publication.

Contemporary Scene


History


Native American Cultures


Natural History and the Environment


The Schoolyard Bioblitz
A bioblitz is an event that focuses on finding and identifying as many species as possible in a specific area over a short period of time. A bioblitz may involve community members, like these students at the National Geographic BioBlitz at the Indiana Dunes National Lakeshore in Porter, Indiana, as well as scientists.

Photograph by Keene Haywood
A bioblitz is an event that focuses on finding and identifying as many species as possible in a specific area over a short period of time. A bioblitz is also known as a biological inventory or biological census. The primary goal of a bioblitz is to get an overall count of the plants, animals, fungi, and other organisms that live in a place.

Species in a bioblitz are categorized into groups that have similar characteristics. These are known as taxonomic groups. Some examples of taxonomic groups include mollusks, vascular plants, fungi, and birds. The end result of a bioblitz is a tally of species found in each of these groups.

A bioblitz differs from a scientific inventory in a number of ways. Scientific inventories are usually limited to biologists, geographers, and other scientists. A bioblitz brings together volunteer scientists, as well as families, students, teachers, and other members of the community.

While a scientific survey often focuses on unique or isolated areas, bioblitzes focus on areas that are connected to residential, urban, and industrial areas.

Finally, biological surveys may take a long period of time to conduct. A bioblitz lasts a short period of time, normally 24 hours. Team members work around the clock to inventory as much as possible in the time given, blitzing the natural area to complete their task.

These differences make a bioblitz a unique biological survey that encourages a relationship between the natural and human communities of a given area. Citizens work alongside scientists to learn about the biological diversity of local natural spaces. In the process, they gain skills and knowledge, and develop a stronger connection to their home environment. A bioblitz aims to promote and improve local natural spaces by empowering citizens to better understand and protect biodiversity.

Hundreds of bioblitzes have been conducted all over the world, primarily in the United States, Canada, Australia, the United Kingdom, and Europe. The first bioblitz was sponsored by the National Park Service and the National Biological Service in Washington, D.C.s Kenilworth Park and Aquatic Gardens in 1996. Surrounded by heavy residential and industrial development, Kenilworth Park was thought to have very little biological diversity. Scientists, however, tallied more than 900 species that first year and added even more species to their list at successive Kenilworth bioblitzes.

In 1997, the Carnegie Museum of Natural History conducted a bioblitz at Pittsburgh, Pennsylvanias Riverview Park. This bioblitz was the first to invite community members to observe the scientists conducting the inventory. Since then, almost all bioblitzes have involved the public.

Bioblitz Programs

The National Geographic Society has conducted a bioblitz every year since 2007. The first National Geographic BioBlitz was held in Washington, D.C.s Rock Creek Park. National Geographic now conducts its BioBlitz in a different national park each year, leading up to the National Park Services centennial in 2016. The 2011 National Geographic BioBlitz will take place in Saguaro National Park, Arizona.
The 2010 National Geographic BioBlitz took place in Biscayne National Park, off Florida's Atlantic coast. The event is considered the United States first marine bioblitz. More than 2,500 people participated in the event, including more than 1,300 school children and 150 scientists.

In 24 hours, participants identified more than 800 species. On land, participants observed a number of species rare to the park, including the silver-banded hairstreak butterfly, mangrove cuckoo, bay-breasted warbler, and nesting roseate spoonbills. The 2010 BioBlitz also identified 22 species of ants that had not previously been documented in the park. Scientists found a number of unique trees, including the paradise tree, Bahama strongbark, and pigeon plum. These specimens are considered the largest of their species in the United States. Underwater, park divers observed marine species, including black, red, and gag groupers, a type of large fish. They also identified 11 species of lichen not previously documented in the park.

Started in 2007, the annual Whistler BioBlitz targets alpine and valley ecosystems across the Whistler region of British Columbia, Canada. Results from each years Whistler BioBlitz have contributed to the Whistler Biodiversity Project, an ongoing effort to catalog and protect the regions biodiversity. Since 2007, participants in the Whistler BioBlitz have documented more than 2,000 species, including 500 species previously undocumented in the area. In 2010, Whistler BioBlitz participants found about 100 previously undocumented species, including dragonflies, truffles, bats, moths, and spiders.

Like many current bioblitz campaigns, the Whistler BioBlitzs species sightings have been put into an interactive map that is available online. Bioblitz maps allow participants to easily input data about their sightings and allow the public to get an in-depth look at their local environment.

Online communication also supports a new variation of the bioblitz: the blogger blitz. Instead of gathering participants to inventory one location, participant blogs pledge to conduct individual surveys of biodiversity in their home areas. These results are compiled and mapped, raising awareness about biodiversity across a larger area.

Environmental organizations have used blogger blitzes to conduct surveys of specific groups of species. The Great Backyard Bird Count, for example, is a four-day count of birds across the United States and Canada that uses online resources and mapping to report its results. These types of events use new technologies to broaden the scope of the bioblitz format, inventorying a greater variety or number of species through a larger network of participants.
Measuring Biodiversity

Just as there are many different ways to define biodiversity, there are many different measures of biodiversity. Most measures quantify the number of traits, individuals, or species in a given area while taking into account their degree of dissimilarity. Some measure biodiversity on a genetic level while others measure diversity within a single habitat or between ecosystems. Measuring biodiversity on the genetic level requires that researchers map the genes and chromosomes of an individual organism and then compare them to the genetic make-up of the larger population. It is genetic diversity which causes tulips to be different colors and different heights. Typically, researchers measure genetic diversity by counting how often certain genetic patterns occur. Another method of measuring genetic diversity works in the reverse: researchers evaluate the differences in physical appearance between individuals then attribute these traits to the most likely genetic roots. Mapping diversity at the genetic level is currently the most accurate measure of biodiversity, although it can be costly and time consuming and, thus, impractical for evaluating large ecosystems. It is most often used to examine managed populations or agricultural crops which can allow for selective breeding of the most desirable traits.

Measuring the diversity of a species generally incorporates estimates of "richness." Also referred to as alpha-diversity, species richness is a common way of measuring biodiversity and involves counting the number of individuals - or even families - in a given area. Researchers have created several indices which measure species biodiversity, the most popular are the Simpson Index and the Shannon Index. These indices focus on the relative species richness and abundance and/or the pattern of species distribution. The Simpson Index takes into account the number of species present and their relative abundance in proportion to the total population. The Shannon Index, originally developed for use in information science, accounts for the order or abundance of a species within a sample plot. The Shannon Index is often used for identifying areas of high natural or human disturbance.

There are also many challenges when measuring species diversity. The greatest of which is a lack of available data. Conducting a full count of the number of species in an ecosystem is nearly impossible, so researchers must use sample plots at a variety of sites but must avoid repetitive counting. Oftentimes, information is not compiled in one specific place, a problem that can lead to an overlap in the naming of species. Another limitation is an inconsistency in treating the definition of species: what one scientist may classify as a new species another may not. At the ecosystem-level, measures of biodiversity are often used to compare two ecosystems or to determine changes over time in a given region. Describing changes in biodiversity within or between ecosystems is called beta-diversity. Measures of beta-diversity indicate the difference in species richness between two different habitats or within a single community at different
points in time. The resulting number indicates to researchers whether there is any overlap in the species found in each group. **Gamma-diversity**, on the other hand, estimates the total biodiversity within an entire region. To arrive at a total estimate, researchers may set up sample plots around the region and count all species within the plots. The sizes of the plots can vary depending on the physical characteristics of the locale. For example, plots in northern forests may be as large as a hectare whereas in dense rainforest a plot might only be a few meters. Another indicator of biodiversity which researchers often track and measure are keystone species, which are integral to ecosystem processes.

Measuring biodiversity on an ecosystem level is thought to be a better way of looking at the health of the entire system, rather than the health of a particular species. However, it faces many of the same challenges measuring species and genetic diversity do - primarily in cost and the lack of standardization. Researchers have only begun taking measurements; this further limits their ability to identify trends since ecosystems tend to change slowly over time. This absence of long-term scientific data remains a particular challenge.

Counting animals and plants, mapping genes, and systematically comparing ecosystems may seem like a lot of trouble for a number that is - ultimately- an estimate. However, the numbers matter. In the field of conservation, biodiversity is often a consideration within an area; being able to quantify what is being conserved is imperative to good planning and management. Labeling a species or ecosystem "diverse" becomes relative; an estimate of biodiversity will have recognizable limitations, like those of imperfect sampling, but will give a comparison or point of reference. The creation of indices gives scientists a standardized tool with which to compare both ecosystem and species health. Therefore, although exact diversity numbers are difficult to yield, knowing how biological resources are distributed within a community can be extremely beneficial in determining both short- and long-term trends.

*Updated by Skyler Treat & Nicole Barone Callahan*
Recommended Resources

Biodiversity Measures (http://rewhc.org/biomeasures.shtml)
The Raytheon Employees Wildlife Habitat Committee defines species richness, the Simpson Index, and the Shannon Index. They also provide information on the assumptions which underlie a good biodiversity estimate.

Simpson's Diversity Index (http://www.countrysideinfo.co.uk/simpsons.htm)
Offwell Woodland and Wildlife Trust, a British wildlife conservation organization, provides a clear explanation of the mathematics and scientific concepts behind the Simpson's Diversity Index.

Just How Many Species Are There, Anyway? (http://www.sciencedaily.com/releases/2003/05/030526103731.htm)
In 2003, Science Daily examined the difficulties associated with measuring the number of species in a large region and how American researcher Michael Rosenzweig and his colleagues dealt with the problem by comparing the accuracy of several different methods.

New Method for Measuring Biodiversity Make It Easier to Identify Key Species (http://www.sciencedaily.com/releases/2008/02/080218172312.htm)
This February 2008 Science Daily article discusses a method developed by Indian and German researchers that weighs the relative importance of species in their ecosystem.

This 2001 academic article from Ecology Letters discussed ways to better quantify the abundance or distributive aspect of species diversity, including detailing the problems of measurement.

Data & Maps
Species Extinction Threat Underestimated Due to Math Glitch (http://www.physorg.com/news134223149.html)
Researchers at University of Colorado Boulder published a study in the July 3, 2008 edition of the journal Nature criticizing current mathematical models used in determining extinction rate. They estimate that extinction rates may actually be 100-fold more than previously thought. Download the related Podcast (http://nature.edgeboss.net/download/nature/nature/podcast/extras/scienceandmusic-2008-06-12.mp3).

The Arthur Rylah Institute for Environmental Research is using different methods to map and measure biodiversity in various regions throughout Australia. Visit their website to see how these different measures are being put to practical use.

Laws & Treaties
The 2010 Indicators (http://www.twentyten.net/target.aspx)
The Biodiversity Indicators Partnership is a means by which countries that are a party to the Convention on Biological Diversity can measure and communicate progress toward set goals. The suggested set of indicators, meant to offer scientists and policymakers standardized measures of biodiversity, include trends in selected ecosystems and genetic diversity, as well as 15 others.
**Viewpoints**

This January 2005 Science opinion piece claims too little science was taken into account when setting the targets for the Convention on Biological Diversity. The authors argue that broadening the spectrum of science involved will lead to better measures of biodiversity.

Continuing the dialogue on appropriate measure of biodiversity, the authors of this May 2005 Science opinion piece argue that a call for a simple measure of biodiversity, such as a biodiversity index, would not accurately reflect the current situation and should be reexamined.

**For the Classroom**

Rocky Intertidal Transect Survey (/article.php/1170.html)
Developed by the Environmental Literacy Council in concert with the College Board, this inquiry-based activity places students in the field to learn about the transect method and statistical analysis used in sampling population abundance and diversity.
[Grades 10-Undergraduate]

Arthropod Diversity (/article.php/1244.html)
Developed by the Environmental Literacy Council in concert with the College Board, this inquiry-based activity is designed to study the biodiversity of arthropods located on a school campus in helping students recognize the relationship between organism type and number to specific habitat. Students will build skills in proper field collection techniques, sampling methods, calculation of biodiversity, quantitative techniques, and field guide use.
[Grades 10-Undergraduate]

Biodiversity Counts (http://www.amnh.org/education/resources/biocounts/plant_id.php)
This curriculum from the American Museum of Natural History focuses on plant identification activities allowing student to measure biodiversity within their own ecosystems. Students also learn how to use a dichotomous key to identify species.
[Grades 6-12]
The Schoolyard Bioblitz

Kim Franklin, Arizona-Sonora Desert Museum
Supported by The Caterpillar Foundation

Teaching Scientific Practices Through an Investigation of Biodiversity: The Schoolyard Bioblitz

Overview
Students will develop an understanding of the concept of biodiversity and the connections between organisms and their environment. They will engage in the scientific process by asking questions about biodiversity in their schoolyards, by designing a plan to carry out a ‘bioblitz,’ analyzing the resulting data, and developing new questions based on their results. The biodiversity data gathered by students during the bioblitz will be shared with other schools as well as scientists through an online data-sharing network called iNaturalist. They will analyze their own data but may also compare their data to data collected by students at other schools. Data analysis will lead to the development of new questions and hypotheses that may be explored in future investigations. In addition to advancing their STEM skills, students will develop a deeper appreciation of nature and an understanding of the importance of biodiversity.

Core Questions
- What are the major components of biodiversity?
- What is a ‘bioblitz’?
- Why is biodiversity important?
- What are the main drivers of biodiversity loss?

Arizona Academic Standards
- Common Core Mathematics:
  Grades 1, 2, & 3:
  Grades 4 & 5: Represent and Interpret Data (bar graphs, pie charts); Extend Understanding of Fraction Equivalence and Ordering
  Grade 6:
  Grade 7: Draw informal comparative inferences about two populations
  Grade 8:
- Science:
  S1C1: Formulate predictions, questions or hypotheses based on observations
  S1C2: Design and conduct controlled investigations
  S1C3: Analyze and interpret data to explain results; Formulate new questions
  S4C3: Analyze the relationships among various organisms and their environment

Next Generation Science and Engineering Practices
- Asking questions (for science) and defining problems (for engineering)
- Planning and carrying out investigations
- Analyzing and interpreting data
- Using mathematics and computational thinking
- Constructing explanations (for science) and designing solutions (for engineering)
- Engaging in argument from evidence
- Obtaining, evaluating, and communicating information
Background

The concept of biodiversity encompasses genetic diversity, species diversity and ecosystem diversity. In this lesson we focus on species diversity, which is arguably the simplest measure of biodiversity. Scientists have formally described nearly 2 million species from our planet, but this total makes up only a small proportion of the actual number of species on our planet, which a recent estimate puts at 8.7 million species, give or take 1.3 million. This means that the overwhelming majority of species on our planet still await discovery!

Who makes up these 2 million described species and over 6 million undescribed species? Animals make up about 1 million of our described species, plants about 250,000 described species, and fungi about 100,000 described species. The remaining species are protists (single-celled organisms that are not bacteria) and bacteria. Within Kingdom Animalia arthropods (animals with exoskeleton and jointed appendages, including arachnids, insects, and crustaceans) make up over 85% of described species.

So why do we care about biodiversity? Biodiversity provides us with myriad natural resources that sustain human life on our planet. The most basic of these resources are clean air and water, which are provided by healthy ecosystems made up of complex webs of interacting species. One of the best examples is that of New York City, which boasts the largest unfiltered water storage and supply system in the nation. In fact the water is purified, but the purification is performed by the soil, microbes, plants and animals in the watershed that lies northeast of the city. Preserving this watershed has eliminated the need to build a water filtration system with an estimated construction cost of $6-8 billion and annual operating costs in the hundreds of millions. Other resources derived from biodiversity include food, medicine, and raw materials used in a wide variety of industries. For example, the FAO estimates that of the slightly more than 100 food crops that comprise over 90% of global food supply, 71 are pollinated by bees, primarily wild bees. Or consider that 25% of prescription drugs in the U.S. contain ingredients derived from plants. Furthermore, there are many values of biodiversity that are more difficult to quantify. How much might the enormous biodiversity of southern Arizona contribute to the value of the region’s tourism industry?

The biodiversity of our planet is declining dramatically. This decline has direct consequences for the human population, such as the loss of species that we once depended upon for food and the deterioration of healthy ecosystems that provide us with a wide variety of services. Human actions are driving this decline in biodiversity. The most significant driver has been habitat loss and degradation. Over 83% of the ice-free land surface has been directly impacted by humanity (Sanderson et al. 2002). The other main drivers of biodiversity declines include invasive species, climate change, and nutrient enrichment, primarily the result of heavy fertilizer use.

Although the biodiversity of our planet is declining overall, scientists have been documenting recent increases in urban biodiversity. In the arid Southwest, you’ll find the highest concentrations of biodiversity in places with water. Increasingly, these places include our cities. For some species, our cities can also be places to find abundant food resources. Consider the floral resources available to bees in our cities or the abundance of rodents and pigeons available to the red tailed hawks and great horned owls that live with us in Tucson. Not only do many of our cities hold a wealth of biodiversity, but these species also perform valuable services for us, free of charge. Recently scientists measured the quantity of food waste processed by ants and other arthropods on the streets on New York City, finding that these animals consume about 14 pounds of food waste per city block per year!
A bioblitz is a rapid biodiversity survey. Conducting a bioblitz in the schoolyard is an excellent way to engage students in science and hopefully give them a sense of appreciation for the biodiversity in their own neighborhoods. Also known as a biological inventory or biological census, a bioblitz is an event in which a group of people attempts to find and document as many species as possible in a specific area over a short period of time. The primary goal of a bioblitz is to get an overall count of the different types of plants, animals, fungi, and other organisms that live in a place. A bioblitz brings together volunteer scientists, as well as families, students, teachers, and other members of the community. Because bioblitzes can be conducted by basically anyone and happen in a short period of time—usually 24 hours—it is a good activity to do in the schoolyard with students. However, bioblitzes have been conducted all over the world. The National Geographic Society conducted one in the Saguaro National Park in 2011. Working together, scientists and the Tucson community documented nearly 1,000 species in the park in just 24 hours. But the desert doesn’t stop at park boundaries. We are excited to start learning about the species that are living with us in our city through the efforts of students across Tucson!

**Recommended Reading**

- National Geographic: Bioblitz - http://education.nationalgeographic.com/education/encyclopedia/bioblitz/?ar_a=1
- National Geographic Bioblitz Educational Resources - http://education.nationalgeographic.com/education/programs/bioblitz/?ar_a=1

**Materials**

Cameras
Pencil and field notebook or Species Observation Worksheet and clipboard
Hand-held GPS system (optional)
Binoculars (optional)

**Day 1: Concept introduction and preparation for fieldwork**

**Core Questions**

- What is biodiversity?
- Why is biodiversity important?
- What is a bioblitz?
- What types of challenges face scientists as they try to measure biodiversity?

**Introduction of Core Concepts**

Introduce the core concepts of biodiversity, species, and bioblitz through the provided presentation or other means.
Optional Activities

Activity 1: (10 minutes) Put students into teams. Give teams a variety of categories for which they are to generate a list of species (e.g., Sonoran Desert species, plants, animals, mammals or endangered species) Allow them to work for 5 minutes, writing down all the species they can think of. The team with the most organisms written down wins.

Activity 2: Watch the video on the 2011 Saguaro National Park Bioblitz and discuss the differences between a bioblitz at the scale of Saguaro National Park versus the scale of a schoolyard or neighborhood.

Have students form groups and design a plan for a bioblitz in the schoolyard. Each group will need at least one camera. If permitted, students may use their phone cameras. If students will be using their own camera, make sure they are capable of transferring the photos they take from their cameras to a computer; they must either have a USB cable to connect their phone to a computer or have email capability on their phone. One or more students in each group should be assigned to be the photographer(s) and official data recorder(s).

Day 2: The Bioblitz

Review the purpose of the bioblitz and have students review their plans. Important reminders for students:

- Photos should allow others to identify the observed species (e.g., photos of plants should include the whole plant, leaves, flowers, and other important parts; photos of insects should be taken at different angles and might include the structures they build)
- Photos should be linked to the written observations on the Species Observation Worksheet or field notebook
- Students should expect to find plants and a variety of animals (mostly insects, but also lizards, birds, and mammals)
- Students should explore all the different habitats present in the schoolyard. Moist areas or areas with standing water are especially good places to look for plants and animals
- Students should spend at least a few minutes sitting quietly to collect observations of lizards, birds, & mammals

GPS Lesson (Optional): See Explanation of GPS, which explains how to use hand-held GPS units to record the precise location of observations.

Get into Groups: Students should have been assigned to groups on Day 1. Remind students of the roles of different group members. At a minimum each groups needs a photographer and official data recorder.

Distribute Materials: Distribute the Species Observation Worksheet and clipboards (optional), GPS units (optional), binoculars (optional), and plant press (optional) to students. Also remind the students to bring their cameras (not optional). If not using the Species Observation Worksheet, students should be prepared to record their observations in a notebook of some sort.

Collect Observations (Conduct the Bioblitz!): Allow the students at least 30 minutes to explore the schoolyard environment and make observations of all species that they encounter.
Species Identification: Most likely the students will not know the names of the majority of the species they observed during their schoolyard explorations. It is not necessary to name each species, but it is necessary to differentiate one species from another in order to tally the total number of species observed during the bioblitz. Species identification does provide students with the opportunity to learn more about the biology and ecology of the organisms they observed. There are several options for species identification:

- Students can work in their groups on identification in the classroom with field guides and other resources (eg. electronic field guides if access to internet is available) provided by teachers/ed specialists. The Easy Field Guide Series from American Traveler Press provides the opportunity to introduce dichotomous keys for certain species groups (eg. cacti).
- Each student can be assigned a number of observations for identification as a homework assignment. A list of identification resources should be provided.
- Students (if using their own cameras) or teachers (if using borrowed cameras) can upload their observations to iNaturalist and invite others to identify the pictured species (see below).

Uploading Observations to iNaturalist: Observations lie at the core of iNaturalist. An observation is basically a species you observed, a time, and a place. Uploading species observations to iNaturalist is easy. Hopefully students will have taken a photo of each species they observed. Although observations without photos may be uploaded, this is discouraged. After all observations are uploaded, iNaturalist will tally the total number of observations and total number of species for you. See the iNaturalist instruction sheet for more information.

Alternative to iNaturalist: If your students do not have access to iNaturalist, you can still create a list of all observations and all species recorded by the class. Remember that the same species is likely to have been recorded by more than one group. Thus your species total will almost certainly be lower than your observations total.

Day 3: Data Analysis and Discussion

Core Questions
- What is a habitat? a microhabitat?
- What do organisms need to survive and reproduce?
- What are native and non-native species?
- What is a descriptive question? a causal question?

Background

Measuring biodiversity is not easy. The simplest measure of diversity is just a count of the total number of species in a given area at a given time. This is known as species richness. There are also a variety of species diversity indices, none of which are without controversy. Calculating species diversity indices requires the collection of abundance data for each species (i.e. the number of individuals observed for each species), which is not the focus of a bioblitz.

A habitat is the place in which an organism lives. Let’s consider a species found in the Sonoran Desert. The Gila woodpecker is a species of bird found throughout the Sonoran Desert in low elevation desert scrub habitat. Although desert scrub is a habitat in its own right, there are many other smaller habitats contained within this larger habitat. Smaller habitats contained with larger habitats are called
microhabitats. For example, cactus rots are important microhabitats within the desert scrub environment. A cactus rot is created when a cactus dies or is damaged and begins to decompose. Many species of bacteria, yeasts, and arthropods make their home in cactus rots.

In the schoolyard, different habitats may be distinguished from each other by differences in landscaping. For example, much of the schoolyard may be irrigated and landscaped mostly with non-native plants, while a portion of the schoolyard may be not be irrigated and planted with only native desert species. We might describe the former as urban desert habitat and the latter habitat as remnant desert scrub habitat. Within each of these habitats we could likely find many different microhabitats.

Data Analysis & Discussion Questions

- Make a bar chart showing the species totals for each schoolyard habitat that was explored. Which habitats within the schoolyard had the greatest species diversity? Why were some habitats more diverse than others?
- Make a bar chart that shows the species totals for plants and animals separately, for each schoolyard habitat that was explored. Which habitats had the greatest diversity of plants and animals? Are these the same habitats for each group of organisms? Why might one habitat support a larger number of plant species while a different habitat supports a greater number of animal species?
- Explain some problems that scientists face when they try to quantify the biodiversity of a given area?
- What happens when new plants are introduced to a habitat? Do they have a negative impact on the native plants growing there?

Optional Activities

Field Guide
Have the class create a field guide for the plants they found. Each page should include a sketch of the plant and a description of its flower, leaves, size, bloom time, and a general description of the habitat, as well as a map of the range where the plant can be found. Gather the field guide pages together to use as reference for studying plants throughout the school year.

Classifying Organisms
To help them study all the varied organisms that live on our planet, scientists have devised a system of classification that includes five different kingdoms—Archaea, Eubacteria (“true” bacteria), Protista, Plantae, Fungi, and Animalia. Have students name three species considered part of each kingdom, with the exception of Archaea, which may not be familiar to most students. Ask students to identify each organism as unicellular or multicellular and to describe its nutrition, movement, and whether it reproduces sexually or asexually.
Introduction

The ability to identify a plant is important for several reasons. From a vegetation management perspective, it is important to know a plant's identity to determine if it is a weed and the level of risk it poses to desired vegetation. Identification is especially important for early detection of new weeds that have never been documented in an area before and can be targeted for eradication. Plant identification is also important for people who raise livestock and are concerned about their animals eating toxic plants. In addition, many people are interested in harvesting edible plants from the wild or their garden and yard. Knowing what plant you are about to eat could become a matter of life or death.

Plant identification can be challenging and even intimidating for the inexperienced. Many people are not comfortable using a dichotomous key and grow weary thumbing through a guidebook page by page until they happen to find a picture that looks similar to the plant they want to identify. However, looking at just a few morphological features of a plant can help you narrow down the options or even identify the plant to genus and species. The purpose of this publication is to cover basic questions you might ask about a plant that will help identify plants with speed and accuracy.

Examples are in the context of noxious weeds, but the concepts can be applied to plant identification in general. This publication will be especially helpful when used in conjunction with your favorite field guide or dichotomous key. Remember to always use multiple features of a plant to determine identity, instead of relying on a single feature. Occasionally there are variations in some of the rules or generalizations presented below, and looking at multiple characteristics helps to avoid errors in identification.

Is the plant a monocot or dicot?

Flowering plants (angiosperms) are split into two types: monocots and dicots. Monocots (mono: one) have a single seed leaf, called the cotyledon, that emerges from the seed, and dicots (di: two) have two seed leaves or cotyledons that emerge from the seed (Figure 1). Grasses are good examples of monocots while a bean or pea is a good example of a dicot. In addition to the number of seed leaves, leaf veins and floral parts help to separate monocots from dicots (Figure 2). Monocots have leaf veins that form a parallel pattern, for example the veins on a blade of grass. Dicots have leaf veins that form a net pattern. Monocots have floral parts (e.g. petals) in multiples of three while dicots have floral parts in multiples of four or five (Figure 3).
From a weed management perspective, recognizing a plant as a monocot or dicot is helpful in regards to herbicide selectivity. Some herbicides, such as plant growth regulators like 2,4-D, target dicots or what are often referred to as “broadleaf” plants. Other herbicides target only grasses, an example of a monocot.

If a plant is a monocot in the grass family (Poaceae), it has additional identifying characteristics that are not covered in this publication. See “Additional Resources” for information on identifying grasses.

How are the leaves arranged?

One of the first and easiest features to observe on a plant is leaf arrangement. Leaf arrangement can be one of three types: opposite, alternate, or whorled (Figure 4). Alternate leaf arrangement is characterized by a single leaf per node. Opposite arrangement is characterized by two and only two leaves at a node on opposing sides of the stem. Leaves are whorled when three or more leaves per node are arranged in a circular pattern. Eurasian watermilfoil (Myriophyllum spicatum) is an example of a noxious weed with whorled leaves. Always examine the whole stem as leaves may be arranged oppositely at the very top but alternately further down the stem.

Are the leaves simple or compound?

A simple leaf is one that is undivided, meaning it has only one definite segment present between the stem and the end of the blade (Figure 5). Compound leaves are divided into definite and distinct segments called leaflets. Compound leaves can be further grouped into pinnately compound leaves and palmately compound leaves. Pinnately compound leaves have leaflets arranged on opposite sides of the leaf axis, similar to a feather. For example, Eurasian watermilfoil leaves are pinnately compound. The leaflets on a palmately compound leaf radiate from a central point, like fingers radiating from the palm of a hand. Sulfur cinquefoil (Potentilla recta) is an example of a noxious weed with palmately compound leaves.

What is the shape of the leaf?

There are many terms used to describe leaf shape. Only seven of the more common leaf shapes are presented here (Figure 6), but guides mentioned in “Additional Resources” provide additional terms and descriptions. Elliptic leaves are broadest in the middle and narrower at either end. Linear leaves are long and narrow with the sides being close to parallel to each other. Lanceolate leaves are much longer than wide, with the widest point below the middle of the leaf. Spatulate leaves look kind of like a spatula, with the tip being rounded and gradually tapering to the base. Ovate leaves are egg-shaped while oval leaves are round to oval, lacking a pointed tip. Cordate leaves are heart-shaped.

What other leaf characteristics are important?

The margin, or edge of the leaf, can also assist in plant identification. As with leaf shape, there are many ways to describe leaf margins. Only three major descriptions are provided here (Figure 7), but check the “Additional Resources” for more information. Entire margins are smooth and do not have any teeth, notches, or divisions. Leaves that have a toothed or saw-like margin are called dentate or serrate. Lobed leaves have indentations along the margin that cut inward toward the leaf midvein.

Another leaf characteristic that can help with plant identification is whether the leaf is petiolate, sessile, or clasping (Figure 8). Petiolate leaves have a stalk (petiole) that attaches them to the stem. Sessile leaves do not have a petiole and are attached directly to the stem. Clasping leaves are sessile (i.e. do not have a petiole)
and have a base that wholly or partly wraps around the stem. The leaves of Dalmatian toadflax (*Linaria dalmatica*) provide a good example of clasping leaves. Whitetop (*Cardaria* spp.) leaves are petiolate on the lower portion of the stem and clasping on the upper portion of the stem.

**What do the flowers look like?**

If a plant is in bloom, flower characteristics provide excellent clues to the plant’s identity. At the same time, flowers are extremely diverse across species and contain many small parts that are sometimes difficult to see with the naked eye or even a hand lens. For that reason, this publication covers only a few broad characteristics that can aid in narrowing the identity of a plant.

**Flower parts (Figures 9-11).**

For most flowers, there is an outermost whorl of leaf-like structures called sepals that protect the bud (Figure 9). Sepals are typically small and green, but may be just as colorful as the petals. Collectively, sepals are called the calyx. The next whorl of leaf-like structures is the petals (Figure 10). They are usually colorful and attractive. Collectively, petals are called the corolla. Some plants don’t have both petals and sepals but just one undifferentiated whorl. For these plants, the petal-like structures are called tepals.
The stamen is the male reproductive organ consisting of an anther, which bears pollen, and a filament, the thread-like structure that supports the anther (Figure 11). Field guides and keys often refer to the number of stamens to help identify a plant. The pistil is the female reproductive organ consisting of the stigma, style, and ovary (Figure 11). The stigma is the tip of the pistil and receives pollen. The style is the narrowed portion that connects the stigma to the ovary. Some flowers have multiple stigmas that field guides and keys will refer to for identification. The pedicel is the stalk that attaches the flower to the stem (Figure 11). The pedicel is to a flower what the petiole is to a leaf (see above, “What other leaf characteristics are important?”).

Flowers in the Asteraceae family are unique in that they may have one or two different types of florets: ray and disc (Figure 12). For example, oxeye daisy has disc florets forming the center yellow portion of the flower and ray florets forming the outer white “petal” portion of the flower. Other plants in the Asteraceae family may have ray florets only or disc florets only (Figure 13). Flowers in the Asteraceae family also have unique features called bracts (Figure 12). These are leaf- or scale-like structures that surround the base of the flower. For certain groups of species, like the knapweeds, bracts are one of the most important characteristics for identification.

**Flower shape.**
Flowers can take many different forms and shapes, but some common shapes are shown in Figure 14. Shapes are helpful to recognize because in some cases they provide very strong clues to which family the plant belongs. For example, all plants in the mustard family (Brassicaceae) like hoary alyssum (*Berteroa incana*), dyer’s woad (*Isatis tinctoria*), and whitetop (*Cardaria draba*) have a cruciform flower shape, four petals that form a cross. A plant with its flower shaped in a head is very likely in the Asteraceae family.

**Inflorescence type.**
Flowers more often than not occur in clusters that have a specific arrangement called the inflorescence. Some of the more common inflorescence types are shown in Figure 15. On a spike, the flower is attached directly to the stem and pedicels (stalks) are absent. On a raceme, pedicels attach the flowers to the stem. Panicles are like compound or branched racemes. In a spike, raceme, and panicle, flowers mature from the base upwards.
A corymb is a type of inflorescence in which the pedicels are different lengths. Pedicels at the base are longer than those near the top, giving the inflorescence a flat to rounded top. An umbel is a flat topped or convex inflorescence with the pedicels arising from a common point, like an umbrella. A cyme is a flat or round topped inflorescence where the terminal flowers bloom first (in contrast to a spike, raceme, and panicle). A helicoid cyme is coiled like a scorpion’s tail and typical of plants in the Boraginaceae family (e.g., houndstongue, *Cynoglossum officinale*, and blueweed, *Echium vulgare*).

**Does the stem have any unique characteristics?**

There are not many terms to learn regarding stems, but stems are worth examining because some plants have unique characteristics that can serve as diagnostic features. Some examples from the noxious weed arena include blueweed (*Echium vulgare*) which has long hairs with dark spots at their base; yellow starthistle (*Centaurea solstitialis*) which has a stem that appears pinched or flattened on each side giving it a “winged” appearance; and Japanese knotweed (*Fallopia japonica*) which has a hollow stem.

**What type of root system does the plant have?**

Although root systems are not obvious without digging up a plant, they can help in identification (Figure 16). Plants with taproots have a single, dominant root that penetrates downward to a considerable depth from which lateral roots sprout. Fibrous roots are densely branching roots that are similar in size with growth oriented both outwards and downwards. Plants with rhizomes have elongated, horizontal, below ground stems that can emerge some distance from the mother plant, giving rise to new plants. Stolons are similar to rhizomes except that the elongated, horizontal stems are above ground. Stolons root at the nodes or tips and give rise to a new plant. From a weed management perspective, plants with taproots like houndstongue are typically easier to hand-pull or dig up than those that are rhizomatous like Canada thistle (*Cirsium arvense*) or stoloniferous like meadow hawkweed (*Hieracium* spp.).
Summary

Plant identification is important and can even be fun. By asking the questions listed above, you will hopefully be on your way to successfully identifying a plant of interest. For further assistance, there are helpful Extension resources. Visit your local county Extension office for more information or access Extension publications at www.msuextension.org/store. You can receive plant identification assistance from the MSU Schutter Diagnostic Laboratory, http://diagnostics.montana.edu.

Glossary

dichotomous key - a reference tool used for the identification of organisms where a series of choices between alternative characters progressively leads to the correct organism; "dichotomous" means “divided into two parts”, therefore dichotomous keys always give two choices in each step

family - group of genera (plural of genus) that resemble one another in certain broad characteristics; family names usually end in –aceae or –ae; for example, Asteraceae or Compositae, the largest family of plants, consists of 950 genera and 20,000 species

floret - very small flowers found in dense arrangements

genus - taxonomic group of related species; first element of a scientific name, examples include Centaurea, Fallopia, Hieracium

morphological - having to do with the form and structure of a plant or animal

node - a joint or point of attachment for leaves and branches

species - a plant or animal with distinct features that can only reproduce with individuals of a similar nature; second element of a scientific name, for example in the name Centaurea stoebe, stoebe is the species

Additional Resources


Special thanks to Linnea Skoglund, Noelle Orloff, and Shantell Frame-Martin for reviewing this publication. All illustrations by Hilary Parkinson.
Resources for Learning and Teaching
PLANT IDENTIFICATION

This guide is available on the KNPS website.

KNPS Members who have contributed to this document are: Nancy Goulden, Phyllis Scherich, Jeff Hansen, Mike Haddock, Karen Hummel and the Board Members who shared their “Words of Wisdom.”

Kansas Native Plant Society, RESOURCES FOR LEARNING AND TEACHING PLANT IDENTIFICATION Copyright © 2007 by Kansas Native Plant Society.
Resources for Learning and Teaching Plant Identification

INTRODUCTION

In the Kansas Native Plant Society Mission Statement, one of the goals related to native plant awareness and appreciation is “promoting education.” Central to helping members, friends, and other interested parties learn about the native plants of our state is to provide materials designed to develop and refine skills of plant identification.

There is no one “right” way to learn plant identification. Many of us just stumbled on what worked for us through trial and error. Others first met plant identification in a botany class. This document shares insights and discoveries from the varied experiences and reflections of KNPS members about plant identification.

Each of the following sections focuses on learners at different identification-skill levels, from novice to those with considerable experience. Most “units” can be used either by individuals working on their id skills alone or as lecture/discussion frameworks for workshops or training sessions. Some suggest a procedure; others focus on resource materials. Sections Coaching Plant Identification and Opportunities to Share Plant Identification Information fit more under the “teaching” category. The sections do not have to be used in the order they appear here. Users can pick and choose whatever fits their needs.
Resources for Learning and Teaching Plant Identification

SECTIONS

I. Teaching Yourself to Identify Native Plants–Gives those who are just beginning to learn about plant identification a process to use independently or with other beginners. Walks the newcomer through the simple basic steps of using a field guide, in a natural setting, to identify and confirm frequently seen plants. Meant to provide the foundation for later, higher-level learning about plant id.

II. How To Get the Most Out of Your Field Guide–Designed for those who have some background and experience in using a field guide for identification, but are now ready to move beyond relying mostly on pictures. Provides many suggestions about using the plant descriptions and special features of the guide to accelerate identification success.

III. What To Do When A “Mystery Plant” Is Not In Your Field Guide–Provides lists of recommended resources including region-specific field guides and books, internet addresses, and Kansas herbariums. This will be very helpful to those with experience in identifying plants who occasionally get stymied by a “new” plant.

IV. Moving Beyond the Basics: Looking at Specific Plant and Location Features–Created for those experienced at identifying plants who are ready to learn and use less obvious features of plant structure and plant habitat for identification. The section includes an extensive check-list of such features to serve as reminders or new clues for distinguishing between similar species or those that are unusually difficult to identify.

V. Guidelines for Coaching Plant Identification–Presents an alternative for those teaching plant identification that goes beyond just naming plants or giving information. Gives coaching strategies that can be used during on-site outings that promote recognition of plant and habitat features, while reinforcing retention of plant information. This section includes techniques that encourage interactions and individual practice that strengthen independent use of the process of plant identification.

VI. Opportunities to Share Plant Identification Information–Here are some suggestions of events and approaches that KNPS members can develop to teach and promote plant identification. Some are related to KNPS events; others focus on occasions that would be available to the public or special interest groups. Included is a section on KNPS Wildflower Patch Classes.

VII. Words of Wisdom from Passionate Native Plant Fans–Individual KNPS members share their favorite advice and suggestions about how to learn plant identification. No two are alike. All are useful and sound.
TEACHING YOURSELF TO IDENTIFY WILDFLOWERS

Target Audience: hobbyists, landowners, and managers who are just starting to learn to identify plants

Often, after being awed by a striking display of wildflowers in bloom, people want to know the names of “that brilliant orange plant” or the “delicate white flower that is everywhere.” Someone who knows the flowers well can provide a name, but for those who want the satisfaction of getting to know, not just the name, but the plant itself better, it may be time to start to teach yourself about our native and introduced plants. The process of identifying a plant is reasonably easy and the excitement of the first time you work out the identity of a plant all by yourself is a life-long memory.

1. Either buy or get from the library a field guide that includes the plants from the geographical and ecological areas (prairie, woodlands) where you will be finding plants. A book with colored pictures, detailed written descriptions, and sketches showing the basic structures of plants is recommended. (Note: if you are primarily interested in identifying grasses or woody plants, you may need a special field guide.)

2. Work on identifying the living plant at the place where it is growing rather than trying to remember the details later.

3. Study the plant for color of bloom, overall structure of the flowering part of the plant, and details such as number of petals.

4. Go to your guide book and find pictures of plants with the same color bloom as “your” plant.

5. Find the picture that most closely resembles “your” plant’s flowers’ shape and arrangement.

6. Now you need to compare other features (e.g. leaves, stems, fruits) with the written description of the plant given in the guide to confirm your tentative identification. Check the field guide glossary for unfamiliar terms. Look in the field guide for sketches of leaf arrangements, shapes, edge and vein patterns.

7. Four easy characteristics that can quickly help you confirm or reject your tentative identification are height of plant, bloom period, habitat and range of plant.
   a. Does the height of the plant match the height stated in the guide?
   b. Does the month/season match the season stated in the guide?
   c. Does the habitat where you found the plant match the description?
   d. Is it found in the part of the state where you found the plant?

8. If any factor does not match your plant, go back to step 4 and try another possibility.

9. Once you are confident you have identified the plant, pat yourself on the back. However, you may also want to talk with either an experienced plant person or someone else who is also learning to
identify plants. In either case, go through your evidence and support your choices step-by-step to the other party.

10. Some plant fans find it helpful to carry a small notebook in which to record the date, general and specific locations of each new plant you identify. Another alternative is to write the date and location in YOUR field guide itself. Either way next time or next year you see the plant, you can come back to your record.

11. Once you have experienced these basic building blocks, you can continue to add more “new” plants and extend your knowledge about botanical terms in the descriptions.

HOW TO GET THE MOST OUT OF YOUR FIELD GUIDE

Target Audience: Hobbyists, Landowners, and Managers with moderate plant-identification experience

1. Familiarize yourself with the guide.
   a. Determine the geographic area covered by the guide.
   b. Determine the type of plants covered by the guide (e.g. prairie wildflowers, woody plants, grasses)
   c. Locate the Glossary. Use it to look up unfamiliar terms.
   d. Locate and refer to sketches of plant structures to confirm your understanding of botanical descriptors.
   e. Check for an Identification Key to identifying plants covered by the guide.
   f. Read the Introduction to the guide. Often it explains how to use the guide.

2. Know how the plants are organized in your field guide.
   a. Check to see if there are separate sections for forbs, woody plants, grasses, sedges and rushes.
   b. Determine the primary factor in the order of the plant pictures in the guide–color? families? other?
   c. If pictures are arranged in color categories, note which colors are in the same sections. For example, purple, blue, and pink may all be in the same section in one book, but not in another.
   d. Within that first organizational scheme (e.g., color, families) determine the secondary order –seasonal blooming order? alphabetical by family? alphabetical by scientific name?
   e. If text describing each species is in a separate section from the pictures, determine how the text descriptions are arranged – by families? What is the order of families?
3. Use the **pictures** to begin to identify plants.
   
a. Find a **picture that best matches** the plant you are identifying.
   b. Look carefully at flowering structures, not just color.

4. Use the **written description of the plant structures such as stems, leaf arrangement and shape, flower arrangement and shape and fruit/seeds appearance** to confirm your tentative identification. Make sure you understand the botanical terms (see Glossary) used in the description. In your personal copy of the field guide in the margin near the text, you may want to write your own translation of the term or make a sketch to help you remember the meaning.

5. Additional clues that can instantly confirm or reject your tentative identification are often found in separate entries from the description of the plant structure. They include **blooming period** (month or season), **sizes** given in text (plant height, leaf width and length, and flower width are often stated); **habitat** where you found the plant (prairie, woodland, roadside and waste places, fields, stream banks); **soil types** where the plant is found (sandy, rocky, clay); **plant’s life cycle** (annual, perennial, biennial)

6. If the picture, description and other features are similar to the plant you are identifying, but not a good match, **note the family of the plant in the field guide**. Then go to the index to find other members of the same family to compare to the plant you are working on.

7. If you still can’t find a match and your field guide has an **Identification Key**, work on keying the plant out.

**WHAT DO YOU DO WHEN A “MYSTERY PLANT” IS NOT IN YOUR FIELD GUIDE**

*Target Audience: Hobbyists, Landowners, and Managers with moderate plant identification experience*

1. Go to additional field guides.

   c. *Tallgrass Prairie Wildflowers* by Doug Ladd and Frank Oberle, Falcon Pr Pub Co (September 2005)
   g. *Oklahoma Wildflowers* by Doyle McCoy, McCoy Publishing Company (March 1987)
   h. *Ozark Wildflowers* by Donald R. Kurz, Falcon Press (1999)
Resources for Learning and Teaching Plant Identification

2. Check more comprehensive books (try a library or the Internet for older books).
   c. *Weeds of the West* edited by Tom Whitson, Cooperative Extension Service (June 1996)
   e. *Flora of the Great Plains* edited by Ted Barkley, University of Kansas Press (June 1986)

3. Try the Internet
   a. Google Search Use if you know the plant’s common name or family.
   b. Mike Haddock’s site: http://www.lib.ksu.edu/wildflower/ Can search plants by color.
   c. Jeff Hansen’s site http://www.kansasnativeplants.com/plantsearch.html Can search by plant characteristics
   d. USDA site: http://plants.usda.gov/ If you think you know plant name, can be used to verify your identification; has maps that show presence of plant in specific counties and states.
   e. KSU Weed ID site: http://www.oznet.ksu.edu/weedmanagement/weedid.asp Good source for weedy plants growing in disturbed soil.

4. Compare notes with other native plant fans in your area
   a. Find a partner or small group to walk with and puzzle out identification together.
   b. Use the KNPS discussion email address: discussion@ksnps.org. Email pictures and questions and let our membership help you ID your plant.

5. Contact a Kansas Herbarium

   Often photographs of the flowers, fruits, or leaves can be e-mailed to the herbarium to identify the plant.

   Some plants need to be examined using magnification to determine the species. For this, take or mail a pressed specimen to the herbarium. Ideally the specimen should contain flowers or fruits, the leaves and the root.

6. Contact a District Conservation Office

   Your District Conservationist at your local Natural Resources Conservationist Services office is another source where you can take in a specimen.
Resources for Learning and Teaching Plant Identification

MOVING BEYOND THE BASICS: LOOKING AT SPECIFIC PLANT AND LOCATION FEATURES

Target Audience: hobbyists, landowners, and managers with moderate plant identification experience.

In order to identify plants that are unfamiliar to you or to differentiate between plants with similar features, it is necessary to become familiar with specific distinguishing features. Below is a checklist of plant structure and plant location details that can be very helpful in identification. Don’t let the length and variety of topics on the list discourage or overwhelm you. You don’t need to learn them all at once. Learning to identify plants is an incremental process. We recommend that you read through the list a couple of times just to begin to alert yourself to some of the possible clues that can improve and speed up your identification skills. You may want to focus on just one category (e.g. leaves) at a time.

As you begin to notice and work with the features, expect to depend heavily on your field guide and other sources. You will need to read carefully the text descriptions in the field guides for each individual plant you are trying to identify, noticing the various features. Refer to the line drawings of plant structures and check the glossary as you encounter new terms.

You may find it useful to carry a 10x hand lens with you when identifying plants in the field to check details too small to see clearly with the naked eye such as hairs on leaves, flowers, and seeds.

i. PLANT STRUCTURES
   1. Inflorescence — the flowering part of the plant and associated structures
      a. Arrangement
         1) Single - one flower on a stem (e.g. violet)
         2) Multiple - flower heads made up of many individual flowers on separate stems (e.g. prairie parsley, milkweed)
         3) Composite - multiple small ray and disk flowers forming what may look like a single flower (e.g. sunflower)
      b. Shape
         1) Regular - symmetrical (e.g. rose family)
         2) Irregular - asymmetrical (e.g. bean family)
      c. Parts associated with the flower head
         1) Petals – colorful part of flower
         2) Sepals – green leaf-like structures below the petals that form the exterior of the floral envelope during the bud stage (e.g. spiderwort)
         3) Bracts – a modified leaf at the base of the flower (e.g. curly-cup gumweed)
         4) Stamen—male part that carries pollen
         5) Pistil—female part
2. Leaves – form from a bud

a. Composition
   1) Leaf – the blade
   2) Petiole – the stem of the leaf, not always present
   3) Stipule – leaf-like structure at base of stem, not always present

b. Arrangement
   1) Opposite (e.g. blue sage)
   2) Alternate (e.g. sunflower)
   3) Whorled (e.g. sweet Joe-pye)

c. Type
   1) Simple – individual leaves (e.g. ironweed)
   2) Compound – leaf composed of smaller leaflets (e.g. tickclover)

d. Shape (e.g. grass-like, heart-shaped, rounded)

e. Edges (e.g. toothed, smooth, lobed, wavy)

f. Bases (e.g. rounded, pointed, square)

g. Tips (e.g. rounded, pointed)

h. Veins
   1) Parallel (not branching, running alongside each other)
   2) Netted (branching in many directions)

i. Texture (e.g. smooth, wooly, hairy)

3. Stems – structure to which the leaves, flowers and fruit are attached

a. Number (e.g. single, multiple)

b. Branching (e.g. none, frequent)
   1) Location (e.g near the base, near the top)
   2) Arrangement (e.g. opposite, alternate)

c. Shape (e.g. rounded, square, triangular, flattened)

d. Position (e.g. upright, along the ground)

e. Surface (e.g. prickles, hairs, wings)

f. Underground
   1) Bulbs (e.g. onion)
   2) Corms (e.g. gayfeather)

h. Reproducing
   1) Stolons – above ground creeping stems rooting at point of contact, (e.g. buffalograss)
   2) Runners – above ground creeping stems rooting at the node, (e.g. strawberry)
   3) Rhizomes – below ground creeping stems, (e.g. Beebalm)

4. Roots - the below ground part of the plant

a. Type
   1) Tap - main tapering root that grows vertically down, (e.g. dandelion)
   2) Fibrous - many branched thin roots, (e.g grasses)
b. Depth
   1) Shallow – weak shallow roots are associated with annual plants
   2) Deep – strong deep roots are associated with perennial plants

5. Fruits - the part containing seeds
   a. Shape (e.g. capsule, pod, berry)
   b. Texture (e.g. ridges, hairs, protrusions)

6. Seeds
   a. Shape (e.g. sphere, disc, kidney)
   b. Texture (e.g. veins, ridges, smooth)

7. Sap (e.g. milky, clear, slimy)

ii. PLANT LOCATION
   1. Region of state (e.g. east ½, southwest ¼)
   2. Physiographic region (e.g. Flint hills, Smokey hills, Ozarks)
   3. Habitats (e.g. prairie, woodland, woodland edges, roadsides, waste places, agricultural lands, stream banks, lake shores)
   4. Soil type (e.g. sandy, rocky, clay)
   5. Slope (e.g. hillsides, valleys, hilltops)

iii. GROWTH FACTORS
   1. Growth habit
      a. Colony forming - spreads by underground or above ground stems
      b. Individual plants - does not spread by stems, only by seed
   2. Above ground growth
      a. Woody - above ground part grows more than one season (e.g. sumac)
      b. Herbaceous - above ground part grows only one season (e.g. goldenrod)

iv. SENSES
   1. Smell (e.g. onion, mint)
GUIDELINES FOR COACHING PLANT IDENTIFICATION

Target Audience: experienced plant-enthusiasts coaching plant identification in the field.

1. Keep in mind the goal is NOT just to tell the name of a plant, but to give participants the tools to identify plants when you are not there.

2. Know and adapt for levels of knowledge and experience (novice, intermediate).

3. Build slowly and incrementally from where participants are.
   a. Don’t overwhelm with too much information at once.
   b. When using botanical terms, explain or paraphrase the term.
   c. Initially use common names of the plants.

4. Structure the walk or hike experience so participants get maximum practice and participation.
   a. Don’t always jump into “lecture mode.” Try these alternatives to promote dialogue rather than monologue.
      1) Sometimes when you approach a new plant ask if anyone knows the name of the plant—if they do, ask them to name it and tell how they know that is what it is.
      2) Or ask if anyone knows the family of the plant or what other plants it reminds them of.
      3) If there is time and participants have field guides, let them singly or as a group try to identify the plant using the field guides, while you coach them on the process.
      4) Encourage relevant questions.
      5) Use techniques to promote understanding and retention.
   b. In the field, point out features about a plant that will help them recognize it next time.
      1) Go beyond the color of the blooms to the leaf, stem, flower, fruit/seed structures by which you identified the plant
      2) Note similarities to and differences from relatives or plants that appear to be similar
      3) Observe the type of location where the plant is growing
   c. Point out clues that will help them remember the name (e.g. meaning and origin of name, translation of terms in name, features the name reflects, silly memory devices)
   d. When a plant is encountered later, either repeat the name and key features, OR reinforce the process and identification by asking the group to name the plant and tell how they know their i.d. is correct.
   e. At the end of the session, ask participants (without looking at notes) to orally construct a list of all the plants they have seen and identified.
Resources for Learning and Teaching Plant Identification

OPPORTUNITIES TO SHARE PLANT IDENTIFICATION INFORMATION

Target Audience: KNPS Board and members who want to conduct training/mentoring

1. The KNPS Annual Wildflower Weekend (AWW)
   a. view plant family CDs
   b. hold short instructional sessions
   c. coach small groups during scheduled hikes

2. Any KNPS sponsored outing
   a. offer a workshop prior to starting walk
   b. coaching at sites for those who want to become leaders

3. A KNPS sponsored workshop
   a. Schedule, organize, publicize an event in the member’s community or several members collaborate in a central location.
   b. Could have special emphases (e.g. how to use a key, botanical terms, tips on leading walks, identifying winter plants)
   c. Use handouts, slides/power point, field guides, plant specimens to introduce processes and concepts.
   d. Include practice (fresh or dried specimens), living plants in natural settings.

4. Prairie Patch Classes
   a. The Patch award is an educational program where the student picks two species of plants, researches them, and identifies them. The application is available on the KNPS web site.
   b. KNPS members can arrange a class either through an already existing organization (scouts, 4-H, summer day camp, local library, after school care, school group) or can offer and advertise a class on their own.
   c. At the first meeting, introduce participants to the Patch materials and give them an introduction to plant morphology and identification.
   d. Arrange for the participants to take part in a KNPS outing. It may be most helpful if you accompany them to the event.
   e. Arrange for participants to visit a location where they can collect data on their two plants. Depending on age and experience, you may want to monitor their progress and be available for questions and help.
   f. Check their completed “booklets” and assist in sending them in.
   g. Either arrange for class members to attend the AWW or be sure they receive their patches (maybe even have a “class reunion” and presentation ceremony).
Resources for Learning and Teaching Plant Identification

Words of “Wisdom”

Members of the KNPS Board share a variety of suggestions and techniques from their experiences identifying plants. As you can tell from their words, building knowledge about native plants is a complex, personal, but very rewarding process.

Identifying plants is easier than most people think. Become familiar with a small number each season and make it a life-long learning process. Each year your new plant friends will greet you with a bloom and you'll say, "I remember you from last season!"

   Valerie Wright

When there are adequate numbers of plants, collect a specimen of the new plant. This will allow you to take it home for identification when you have more time, resources, etc. After ID'ing it, press and mount it with the appropriate labeling. This will enable you to review it and refer back to it the next time you see it. It also will allow you to compare it to other plants in its family to see how they are similar and different. Photos with appropriate labels also are a great help.

   Phyllis Scherich

I always bring a pocket sized notebook and pencil to outings to record the names of the plants (or birds, insects, reptiles, rocks, mushrooms, etc.) that I want to learn more about later from resources at home. It's also very memorable to learn something useful about each plant; for example, is it a favorite food for certain caterpillars or other animals? Is it edible, medicinal, or poisonous? Etc. And I like to experience a new plant w/another sense in addition to sight: feel the leaves' smoothness/roughness, smell the flower or a crushed leaf.

   Shirley Braunlich

I always try to get people to notice the leaf arrangement, basic flower structure, and specific family characteristics such as square stem. I encourage them to attempt identification themselves by looking for simple characters that they can recognize.

   Iralee Barnard

As one who came to plant identification relatively late in life, I have been challenged to sort out wildflowers by the only two labels we're likely to hear: "genus" and "species." Then I realized that most of the botanical whizzes walking beside me were quietly using "family" as their first clue in identifying a mystery forb. A few plant families, most with quite distinctive features, contain a high proportion of the native plants we see, so I now knowingly say "it looks like an aster" (or "milkweed," or "bean") and go home feeling much younger.

   Fred Coombs
Resources for Learning and Teaching Plant Identification

When you photograph a plant, try to get the leaf, stem, flower, and seeding strategy (capsule, pod, etc). In your notes: type of soil, part of state, local topography, condition of soil (moist-dry...).

Sister Patricia Stanley

As for plant ID, in the beginning the scientific name seemed almost too difficult to learn. But as I slowly progress, common names seem far more challenging because they are so variable. I think it actually saves time and confusion to tackle a single scientific name for a plant than to try to remember several locale-specific names for a single plant, some of which may also be tacked onto a different plant!

Nancy Coombs

For beginners, learn to recognize the plant in its natural surroundings. Make a mental note about where it is located. Is it growing in thin soil with rocks or is it in a wetland? Observe closely, jot down characteristics, or take a picture of flowers and leaves. With the aid of regional plant ID books, the plant will likely be identified.

Cindy Ford

It helps me remember a new plant (or bird) when I take time to note in my favorite ID book where and when I first saw it. If it's similar to other species, I underline the distinguishing characteristics. If I'm not sure what I'm looking at, if possible, I press a sample in my book and find a "pro!"

Ann Feyerharm

I would recommend that you find a person who is a level or two above you in identifying plants and pick their brain as you drag them off into the prairie. I also would suggest that you attend wildflower walks whenever possible and most assuredly you should join the KNPS or other groups to find others in your area who would enjoy sharing their knowledge and love for our native plants with you. A modest selection of books is necessary to advance your knowledge, and eventually you will learn to see the similarities that group the plants into related families and genera. And finally, never be afraid to ask others for help!

June Kliesen

When identifying plants, it’s important to look at more than just the flower. Look at the flower in detail, count the petals; touch the leaves, what is the texture; pick a leaf, is there milky sap; smell the crushed leaf, what is the odor; look at the leaf arrangement, are the leaves opposite; look at the stem, what is its shape. I find it useful to study your field guides before you go out. That way when you see something, it might trigger your brain - hey I saw that in my field guide, it's blah blah blah.

Jeff Hansen
Become acquainted with a knowledgeable plant enthusiast. It always helps to have someone to ask for help with identification and to suggest good places to look for new, unusual, interesting plants.

   Earl Allen

My insight is that when I tell people what these plants are, they can look up plants and learn all about them.

   Carl Paulie

Find a plant ID partner who is about at the same level of expertise as you are and go out to natural areas on a regular basis. Two sets of eyes, two different minds, and constant challenges or confirmation of each other's identification will let you learn twice as many plants in half the time.

   Nancy Goulden
A Pictorial Key to the Order of Adult Insects

winged

front wings hardened, leathery or parchmentlike at least at the base

chewing mouthparts

without pincer-like cerci

dermaptera (earwigs)

with pincer-like cerci

hemiptera (true bugs)

sucking mouthparts

front wings membranous (go to page 61)

front wings of uniform texture

front wings leathery at base and membranous at end

dictyoptera (roaches, mantids, walkingsticks)

orthoptera (crickets, katydids, grasshoppers)

dictyoptera (roaches, mantids, walkingsticks)

A. hind femur enlarged
B. tarsi with four or fewer segments

COLEOPTERA (beetles)

A. hind femur not enlarged
B. tarsi with five segments

A

A

A

A.
two wings

A. pronotum extended over abdomen

ORTHOPTERA (pigmy grasshoppers)

B. pronotum not extended over abdomen

four wings

wings with few or no scales; without coiled proboscis

A. wings usually covered with scales

B. mouthparts consist of coiled proboscis

LEPIDOPTERA (butterflies and moths)

very slender wing with fringe of hairs as long as wing is wide

THYSANOPTERA (thrips)

no fringe of hairs, or if present, not as long as wing is wide

end of abdomen without noticeable appendages

end of abdomen with style or thread-like tail

A. with haltere-like organs in front of wings

COLEOPTERA (male stylopids)

B. with halteres behind wings

DIPTERA (flies, mosquitoes, gnats, midges)

A. style-like tail

HOMOPTERA (male scales)

B. two or three thread-like tails

EPHEMEROPTERA (mayflies)
A. piercing-sucking mouthparts

HOMOPTERA
(cicadas, leafhoppers, planthoppers, spittlebugs)

B. chewing mouthparts

HYMENOPTERA
(bees, wasps, ichneumons)

TRICHOPTERA
(caddisflies)

A. antennae shorter than body; no noticeable scales

B. antennae as long as body; wings and body often with scales

EPHEMEROPTERA
(mayflies)

Hind wings equal to or larger than front wings (go to page 63)

Hind wings smaller than front wings

No long abdominal appendages

Abdomen with two or three thread-like tails

Tarsi two or three segmented

Tarsi with more than three segments (usually five)
continued from key page 62

mouthparts close to eye

mouthparts at end of beak-like structure some distance from eye

wings never held flat over abdomen

A. bristle-like inconspicuous antennae

B. antennae apparently with several segments

ODONATA (dragonflies, damselflies)

NEUROPTERA (lacewings, mantispids, owlflies, antlions)

hind wings with enlarged anal area folded fan-like; wings tend to curl around the body lengthwise

MEGALOPTERA (dobsonflies, fishflies, alderflies)

hind wings without enlarged anal area folded fan-like; wings do not tend to curl around the body lengthwise

NEUROPTERA (lacewings, mantispids, owlflies, antlions)

all legs of walking type

hind legs modified for jumping

ORTHOPTERA (tree crickets)

A. cerci usually long; more than eight segments

B. cerci short; with two to eight segments

PLECOPTERA (stoneflies)

ISOPTERA (termites)
continued from key page 60

antennae present

- legs present
  - A. collophore present;
  - B. spring-like organ usually present

  DIPTERA
  (louse flies, bat flies)

- legs absent
  - head and thorax separate

  HOMOPTERA
  (scales)

  COLEOPTERA
  (female stylopoids)

antennae absent

- legs present
  - both collophore and spring-like organ absent

  COLEMBOLA
  (springtails)

- legs absent
  - head and thorax fused

  THYSANURA
  (silverfish)

A. collophore present;
B. spring-like organ usually present

A. body flattened laterally
B. or dorsoventrally

body not flattened

(goto page 66)

(goto page 65)
body flattened dorsoventrally

sucking mouthparts externally visible

A. antennae longer than head

B. antennae shorter than head

antennae longer than head

antennae shorter than head

HEMIPTERA (true bugs)

DIPTERA (louse flies and bat flies)

PSOCOPTERA (booklice, barklice)

DICTYOPTERA (roaches, mantids, walkingsticks)

A. head wider than thorax at point of attachment to thorax

B. head narrower than thorax at point of attachment to thorax

MALLOPHAGA (biting lice)

ANOPLURA (sucking lice)

continued from key page 64

body flattened laterally

no sucking mouthparts externally visible

SIPHONAPTERA (fleas)
continued from key page 64

abdomen and thorax not narrowly joined together

- body covered with scales
  - LEPIDOPTERA (female cankerworm)

- body not covered with scales
  - tarsal claws absent
    - THYSANOPTERA (thrips)
      - piercing-sucking mouthparts
      - A. cornicles usually present
        - with distinct head and eyes
          - HEMIPTERA (bed bugs)
        - without distinct head and eyes
          - HOMOPTERA (female scales)

  - tarsal claws present
    - chewing mouthparts
    - HYMENOPTERA (ants)
      - A. cornicles absent

abdomen and thorax narrowly joined together

- body covered with scales

- body not covered with scales
  - dermaptera (earwigs)
    - abdominal forceps absent
      - entire body rather hard and brown colored
      - (go to page 67)

  - dermaptera (earwigs)
    - abdominal forceps present
A. mouthparts at end of beak-like structure some distance from eye

B. antennae shorter than one-fourth of body length

C. antennae longer than one-third of body length

MECOPTERA (scorpionflies)

PSOCOPTERA (barklice and booklice)

COLEOPTERA (female stylopids)

ORTHOPTERA (crickets)

ISOPTERA (termites)

continued from key page 66
Appendix
Vocabulary List

Alien species: Species introduced into ecosystems that are outside normal distribution areas.

Annual plant: A plant which completes its life cycle from seed germination, through reproduction, to death within one year.

Archaeologist: A person who studies past human history by digging up artifacts and remains, such as pottery, tools, and homes.

Arthropod: An invertebrate animal that has an exoskeleton, jointed legs and many body sections. A beetle is an arthropod.

Bioblitz: An effort that enlists the help of both scientists and non-scientists in documenting as many species as possible in a defined area over a short period of time ('bio' = life; 'blitz' = fast).

Biodiversity: The diversity, or variety, of plants and animals and other organisms in a particular area or region; this includes diversity within species, between species, and of ecosystems.

Biotic community: The plants and animals living and interacting with each other and with their physical environment in a given locality, such as in a salt marsh or in a bursage-creosote community.

Camouflage: An animal’s color patterns that help it blend in with the plants or rocks around it.

Carnivore: An animal or plant (particularly insect- and invertebrate-eating plants) that requires a staple diet consisting mainly or exclusively of animal tissue through predation or scavenging.

Climax community: Fairly stable, self-sustaining community in an advanced stage of ecological succession; usually has a diverse array of species and ecological niches; captures and uses energy and cycles critical chemicals more efficiently than simpler, immature communities.

Commensalism: An interaction between organisms of different species in which one type of organism benefits from the other without affecting it.

Competition: An interaction between individual organisms (intraspecific competition) or species (interspecific competition) in which both the species are harmed. Limited supply of at least one resource (such as food, water, and territory) that is used by both organisms can be a factor in competition.

Deciduous plant: A plant that drops its leaves seasonally in response to a dry or cold period.

Decomposer: Organisms that break down dead or decaying plants or animals and return nutrients to the soil. Examples: termites, bacteria, millipedes, and fungus.

Disturbance: A discrete event that disrupts an ecosystem or community. Examples of natural disturbances include fires, hurricanes, tornadoes, droughts, and floods. Examples of human-caused disturbances include deforestation, overgrazing, and plowing.

Diurnal: Active during the day.

Dormancy: The temporary suspension of biological activity, such as growth or movement.

Drought: Prolonged and widespread deficit in naturally available water supplies, such as rain or snow.

Ecological succession: Process in which communities of plant and animal species in a particular area are replaced over time by a series of different and often more complex communities.
Ecology: The study of interrelationships among plants, animals and their physical environments. Ecosystem: A community of interacting living organisms and non-living physical components of an environment, through which energy moves and minerals are recycled; e.g., a small mud flat or the biosphere.

**Ecosystem services:** The benefits that people obtain from ecosystems. These include provisioning services such as food and water; regulating services such as flood and disease control; cultural services such as spiritual, recreational, and cultural benefits; and supporting services such as nutrient cycling that maintain the conditions for life on Earth.

**Ectothermic:** An animal that regulates its body temperature largely by exchanging heat with its surrounding environment; a cold-blooded animal.

**Endangered:** A plant or animal species that exists in such small numbers that it is in danger of becoming extinct.

**Endemic:** Growing or living exclusively within a particular region or locality, such as an island, nation, country or other defined zone, or habitat type

**Evaporation:** The sum of water lost from a given land area during any specific period of time by evaporation from water surfaces, moist soil, and snow, and by transpiration from vegetation and the building of plant tissue.

**Exoskeleton:** A hard outer structure, such as the shell of beetles and other arthropods, that provides protection or support for an organism.

**Exotic species:** Species that migrate into an ecosystem or are deliberately or accidentally introduced into an ecosystem by humans.

**Extinct:** When the individual of a species dies; or when a species is reduced to such low abundance that, although it is still present in the community, it no longer interacts significantly with other species. Food Chain: A group of animals and plants in a community through which energy flows in the form of food.

**Fossil:** The remains or impression of a prehistoric organism preserved in petrified form or as a mold or cast in rock.

**Foundation species:** Species that plays a major role in shaping communities by creating and enhancing a habitat that benefits other species.

**Habitat:** The place in which a plant or animal naturally lives that provides food, water, shelter and space. Habitat fragmentation: Process by which habitat loss results in the division of large, continuous habitats into smaller, more isolated remnants.

**Herbivore:** An animal that eats only plants.

**Hibernate:** To be in a dormant or torpid state during a cold period, especially during the winter.

**Host:** Plant or animal on which a parasite feeds.

**Hybrid:** Offspring which is the product of cross-fertilization between two different species, subspecies or varieties.

**Immature community:** Community at an early stage of ecological succession. It usually has a low number of species and ecological niches and cannot capture and use energy and cycle critical nutrients as efficiently as more complex, mature communities.

**Indicator species:** Species that serve as early warnings that the health of a community or ecosystem is being degraded.

**Inertia:** Ability of a living system to resist being disturbed or altered.

**Interspecific competition:** Individuals of different species compete for the same resource in an ecosystem.

**Intraspecific competition:** Individuals of the same species compete for the same resource in an ecosystem.
**Invasive species**: A non-native (or alien) species whose introduction causes or is likely to cause economic harm, environmental harm, or harm to human health.

**Keystone species**: Species, often dominant predators, that play a role in an ecosystem that affects many other organisms; removal of keystone species often allows a prey population to explode and decreases overall diversity.

**Mammal**: A warm-blooded, vertebrate animal of a class that is distinguished by the possession of hair or fur, the secretion of milk by females for the nourishment of the young, and (typically) the birth of live young.

**Mano**: A hand-held grinding stone. Mature community: Fairly stable, self-sustaining community in an advanced stage of ecological succession; usually has a diverse array of species and ecological niches; captures and uses energy and cycles critical chemicals more efficiently than simpler, immature communities.

**Mesic**: Of or pertaining to a habitat that has a moderate amount of moisture, such as a riparian area or cienega. Compare to xeric.

**Metamorphosis**: The process of physical transformation (in an insect or amphibian) from an immature form to an adult form in two or more distinct stages.

**Metate**: A stone base which holds corn and mesquite pods for grinding with a mano.

**Microhabitat**: A smaller, more specific habitat within the larger habitat in which a species lives, e.g. under a rock, on a certain species of plant.

**Mutualism**: Type of species interaction where organisms of different species exist in a relationship in which each individual benefits from the activity of the other.

**Native species**: Species that are indigenous to a given region or ecosystem; their presence in the region is the result of only natural process, with no human intervention.

**Niche**: The role or function of a particular species in its community or ecosystem.

**Nocturnal**: Active at night.

**Non-native species**: A species that is not indigenous to a given region or ecosystem. Compare to Native species.

**Omnivore**: An animal that eats either other animals or plants.

**Orographic**: Pertaining to mountain-building or orogeny.

**Paleontologist**: A scientist who studies past forms of life by examining fossils.

**Parasite**: Consumer organism that lives on or in and feeds on a living plant or animal, known as the host, over an extended period of time. The parasite draws nourishment from and gradually weakens its host; it may or may not kill the host.

**Pathogen**: Organism that produces disease.

**Perennial**: Plants that are present at all seasons of the year and persisting for several years, usually with new herbaceous growth.

**Petroglyph**: A rock carving created by prehistoric peoples; typically a picture of animals, hunters, and scenes of daily life.

**Pictograph**: An ancient or prehistoric drawing or painting on a rock wall.

**Pioneer community**: First integrated set of plants, animals, and decomposers found in an area undergoing primary ecological succession.

**Pioneer species**: First hardy species, often microbes, mosses, and lichens, that begin colonizing a site as the first stage of ecological succession.
Pollination: The process by which pollen is moved from the male parts of one flower to the female parts of another flower of the same species. Pollination is a precondition for seed set and the development of fruit in most plants.

Population: all of the individuals of the same species within an ecological community.

Predation: Situation in which an organism of one species (the predator) captures and feeds on parts or all of an organism of another species (the prey).

Predator: An animal that kills other animals for food. (Try not to think of a predator as the enemy of the prey. A predator is simply getting its food in the way in which it is best adapted.)

Prey: An animal that is hunted for food by a predator. Example: a kangaroo rat may become prey for a coyote.

Primary succession: Ecological succession in a bare area that has never been occupied by a community of organisms.

Reptile: An animal that has dry, scaly skin, lays eggs, and is ectothermic. Snakes, lizards, and tortoises are reptiles.

Resilience: Ability of an ecosystem to respond to a perturbation or disturbance by resisting damage and recovering quickly.

Scavenger: An animal that is either carnivorous or herbivorous and feeds on dead animal and plant material present in its habitat.

Secondary succession: The ecological succession that occurs on a preexisting soil after the primary succession has been disrupted or destroyed due to a disturbance that reduced the population of the initial inhabitants.

Species: A distinct type of organism capable of reproducing with other individuals of the same type, but not with any other type of organisms. (For example, a fox and a coyote are similar, but they cannot breed with each other. A fox is one species and a coyote is another.)

Species evenness: Abundance of individuals within each of the species contained in a community.

Species richness: The number of species in a given area.

Succession: See ecological succession, primary succession, secondary succession.

Succulent: A plant that has thick or fleshy leaves and stems that retain water in arid climates or soil conditions.

Symbiosis: A close ecological relationship between the individuals of two (or more) different species; the term is often used to describe relationships that are mutually beneficial but it also includes other relationships. See commensalism, mutualism and parasitism.

Taxonomy: The science of finding, describing, classifying, and naming organisms.

Threatened: Plants or animals whose populations are decreasing and may become endangered.

Threshold effect: The harmful or fatal effect of a small change in environmental conditions that exceeds the limit of tolerance of an organism or population of a species.

Tolerance limits: Minimum and maximum limits for physical conditions (such as temperature) and concentrations of chemical substances beyond which no members of a particular species can survive.

Venom: A substance which may contain hemotoxins and/or neurotoxins and causes pain, paralysis, and/or death when injected by mouthparts (including fangs) or stinger.

Venomous: An animal that is capable of injecting venom by means of a bite or sting.

Xeric: Of or pertaining to a dry habitat such as a desert, or adapted to a dry habitat. Compare to mesic.
Arizona Science Standards

Composed of 6 strands and (up to) 5 unifying concepts per strand

Strand 4: Life Science
Understanding life by focusing on the characteristics of living things, the diversity of life, and how organisms and populations change over time in terms of biological adaptation and genetics. This includes the relationship of structures to their functions and life cycles, interrelationships of matter and energy in living organisms, and the interactions of living organisms with their environment.

Strand 5: Physical Science
Students gain an understanding of the nature of matter and energy, including their forms, the changes they undergo, and their interactions. By studying objects and the forces that act upon them, students develop an understanding of the fundamental laws between systems and surroundings.

Strand 6: Earth and Space Science
Understanding the Earth, its history, composition, and formative processes, and understanding the solar system and the universe. Students study the regularities of the interrelated systems of the natural world.

Strands 1, 2, and 3 are designed to be explicitly taught and embedded within each of the content strands 4, 5, and 6, and are not intended to be taught in isolation:

Strand 1: Inquiry Process
Students use scientific processes: questioning, planning and conducting investigations, using appropriate tools and techniques to gather data, thinking critically and logically about relationships between evidence and explanations, and communicating results.

Strand 2: History and Nature of Science
Emphasizes the importance of the inclusion of historical perspectives and the advances that each new development brings to technology and human knowledge. This strand focuses on the human aspects of science and the role that scientists play in the development of various cultures.

Strand 3: Science in Personal and Social Perspectives
Students develop the ability to design a solution to a problem, to understand the relationship between science and technology, and the ways people are involved in both. Students understand the impact of science and technology on human activity and the environment. Students understand their place in the world – as living creatures, consumers, decision makers, problem solvers, managers, and planners.
Next Generation Science Standards

Framework for Science Education Goals

- Focus on learning as a developmental progression (Disciplinary Core Idea Progression)
- Integrate the content knowledge of scientific explanations and the practices needed to engage in scientific inquiry and engineering design (Science and Engineering Practices)
- Provide a limited number of core ideas in science and engineering to avoid the shallow coverage of topics (Crosscutting Concepts)

Disciplinary Core Idea Progression

Increasing sophistication of student thinking from grade band to grade band:
(K-2, 3-5, 6-8, 9-12)

Science and Engineering Practices

1. Asking questions (for science) and defining problems (for engineering)
2. Developing and using models
3. Planning and carrying out investigations
4. Analyzing and interpreting data
5. Using mathematics and computational thinking
6. Constructing explanations (for science) and designing solutions (for engineering)
7. Engaging in argument from evidence
8. Obtaining, evaluating, and communicating information

Crosscutting Concepts

1. Patterns: Observe how patterns of forms and events guide organization and classification, prompt questions about relationships and the factors that influence them.
2. Cause and effect: A major activity of science is investigating and explaining causal relationships and the mechanisms by which they are mediated. Such mechanisms can then be tested across given contexts and used to predict and explain events in new contexts.
3. Scale, proportion, and quantity: In considering phenomena, it is critical to recognize what is relevant at different measures of size, time, and energy and to recognize how changes in scale, proportion, or quantity affect a system’s structure or performance.
4. Systems and system models: Defining the system under study—specifying its boundaries and making explicit a model of that system—provides tools for understanding and testing ideas that are applicable throughout science and engineering.
5. Energy and matter: Flows, cycles, and conservation. Tracking fluxes of energy and matter into, out of, and within systems helps one understand the systems’ possibilities and limitations.
6. Structure and function: The way in which an object or living thing is shaped and its substructure determine many of its properties and functions.
7. Stability and change: For natural and built systems alike, conditions of stability and determinants of rates of change or evolution of a system are critical elements of study.