



Desert Laboratory on Tumamoc Hill Science and Education Strategic Plan

The Future of Life in the Desert

Building resiliency in arid lands through science-based solutions

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Desert Laboratory Science Steering Committee
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Executive Summary

For humans to continue to live in arid lands, we must understand how we can live sustainably in the face of climate change and other trending stresses on linked human and natural systems of the desert. **The role of the Desert Laboratory is to build on the complementary strengths of culture, science, and community rooted at Tumamoc Hill and the larger Sonoran Desert to become an integrative hub of novel research, education, and outreach about how linked human and natural systems face the future of life in the desert.** Grounded in community needs and solution driven, the work of the Desert Laboratory will involve diverse stakeholders to collaboratively meet challenges that affect all life in the desert.

To achieve this vision, we propose to conduct and facilitate this research and outreach through four complementary mechanisms.

1. **Increase support for place-based field research** that integrates long-term data with novel research questions at Tumamoc Hill, the larger Sonoran Desert, and arid lands generally. This work will be conducted by a community of researchers anchored at the Desert Laboratory with diverse funding bases and home units.
2. **Convene transdisciplinary working groups to address priority issues facing the future of life in arid environments.** The Desert Laboratory will solicit proposals for new collaborations with diverse stakeholders that will accelerate innovative solutions to the challenges of future life in the desert, while building on the Desert Lab's core strengths. The University of Arizona through the Desert Laboratory will provide resources and space for concentrated collaboration on specific issues in the form of multiple intensive meetings over a period of six months to two years.
3. **Establish the Tumamoc Institute of Science, Culture, and Art.** The public prominence of Tumamoc Hill affords the Desert Laboratory a remarkable opportunity to communicate the results of its research, as well as involve the public. The Tumamoc Institute coalesces the Lab's suite of public programs into a self-sustaining financial model.
4. **Offer undergraduate and graduate education courses on the future of life in the desert.** Training the next generation of researchers and thinkers is fundamental to the University and the Desert Laboratory. Undergraduate and graduate experiential courses will root students in a sense of place and help develop core competency in resilience thinking and science.

A. Introduction

The Desert Laboratory is located on Tumamoc Hill, a volcanic hill of prominent cultural and sacred significance to the Tohono O’odham, including the San Xavier Wa:k District, and other Native nations. The current significance of the Hill for the Tohono O’odham and other nations is holistically rooted in religion and ceremony, language, oral and ecological traditions, and connection to this ancestral landscape. The Desert Laboratory recognizes the cultural importance of *Cemamagi Du’ag*, Horned Lizard Mountain, and surrounding environs as the bedrock of the laboratory and our future actions.

Founded in 1903 by the Carnegie Institution, the Desert Laboratory on Tumamoc Hill has repeatedly been at the center and forefront of desert research. The original focus was primarily on ecology, especially of plants, with the later addition of paleoecology using fossil pollen and packrat middens in the 1960s. Archaeological research on the Hill started in the late 1970s. Most recently, a strong public outreach component has developed as Tumamoc has become one of the most popular outdoor recreational locations in Tucson, with over 350,000 annual visits. However, these cultural, scientific, and community foci have operated largely independently, so that their great potential for synergy has gone unrealized (Figure 1).

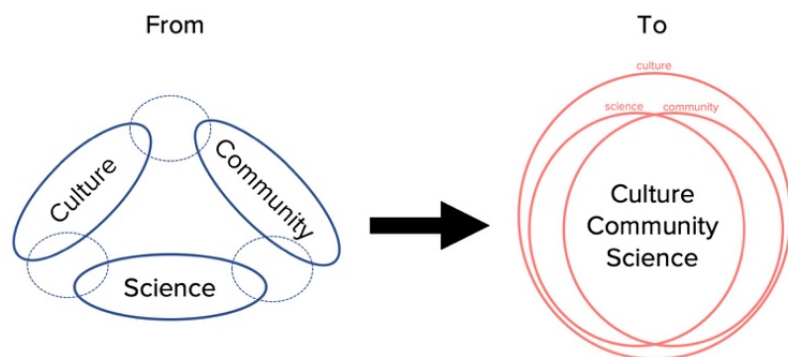


Figure 1. Conceptualization of the shift from a largely independent view of culture, community, and science to a place of integration and unification.

From the 1960s to the early 1990s, if one wanted to investigate questions of arid lands, the University of Arizona was the unquestioned leader in the field; that leadership, however, is not as clear as it once was. Dissolution of the Office of Arid Land Studies, the previous waning of the Desert Laboratory, and strategic investments in other areas left a gap in the ability of the University to leverage its strength in desert studies. Importantly, however, these strengths remain in abundance, though are scattered across campus, including the Southwest Center, the Arid lands Resource Sciences graduate program, multiple climate programs, and numerous faculty in nearly every college of the University. The establishment of the Arizona Institutes for Resilience (AIR) and the inclusion of the Desert Laboratory as part of AIR provides the opportunity for the University of Arizona to once again combine and build on these strengths and be the international leader in desert research.

Under the leadership of Dr. Ben Wilder, the Desert Lab is entering a new era. Over the previous three years, several core areas of need have been resolved and new partnerships and initiatives have been developed (Appendix 1). The foundation is now in place for transformative investment that can realize the Desert Laboratory as an international leader of desert thinking.

B. Four complementary mechanisms to address the future of life in the desert

1. Increase support for place-based field research

The Desert Laboratory was founded on Tumamoc Hill to answer the fundamental question: how does life cope with aridity? In the twenty-first century, increasing drought and heat in many parts of the globe have transformed this basic scientific question into an urgent challenge facing humanity. Ongoing research at the Desert Laboratory addresses our changing environment through a diversity of perspectives and disciplines that coalesce to find answers. The Lab itself serves as an intellectual watering hole where researchers both focus their efforts and share knowledge.

The Lab includes numerous critical resources that underpin place-based research, including the following long-term plots, collections, and facilities:

- The University of Arizona Vertebrate Paleontology collection
- The North American Fossil Packrat Midden collection
- The Sonoran Desert pollen reference collection
- The Desert Laboratory Repeat Photography collection (curated by the USGS)
- Sonoran Desert Library
- The Spalding 110-year-old vegetation plots
- The world's oldest long-term saguaro plots
- Dr. Larry Venable's annual plant study plots with 37+ years of data
- Detailed archaeological site data for the top of the Hill and the Hohokam agave fields
- 115 years of site-specific meteorological data
- Tucson's first and still active greenhouse
- The Sonoran Desert Plant Garden

These legacy collections, data sets, and resources will be incorporated into projects that pivot on a forward-looking version of the original guiding question of the Desert Lab—how will life adapt to aridity?

We propose to expand the support for these resources and research on the 860 acres of Tumamoc Hill and the Sonoran Desert at large through funds for seed money to catalyze new projects, sustain long-term data collection, curate current collections, coordinate research, and provide logistical assistance. The renewed place-based focus will strive to equally balance ecological and cultural disciplines, which have largely remained within their own spheres until now.

Project titles of innovative research based at the Desert Laboratory are presented here, with synopses in [Appendix 2](#).

- **The shifting boundaries of the Sonoran Desert**
Currently supported, 2019–2024, \$2.6M Collaborative NSF grant with University of Oregon, Arizona State University, and California State Sacramento.
- **Tumamoc arts working group**
With support from the UArizona Confluentcenter (\$15,000, 2018–2020), the working group was established in 2018, consists of 15 individuals, and is actively undertaking its first project with the Indigenous aerosol arts collective Neoglyphix. More information is available here: <https://tumamoc.arizona.edu/tumamoc-arts-working-group>
- **Buffelgrass and the Anthropocene**
Currently supported, 2020–2021, \$105,000 grant with Arizona-Sonoran Desert Museum and active restoration research by the Gornish Lab in the College of Agriculture and Life Sciences.
- **Tracking the Pulse of the Desert**
Currently supported, 2020–2021 with a grant from the National Park Service (\$75,000). The effort is in collaboration with Saguaro National Park Desert Lab and with an Ike Russell postdoctoral scholar to be brought on board in summer 2020.
- **Aridamerica Food Resilience**
Developing grant and foundation proposals at present with Dr. Gary Nabhan and B2.
- **Human and Paleoenvironmental History of the Arid Core of the Sonoran Desert**
Currently developing grant proposals for a recent archeological discovery in northwest Sonora, Mexico.
- **Hindsight: Using the Lens of Repeat Photography with Community Science to Track Change across the Landscape**
Collaboration with the United States Geological Survey has been initiated and grant proposals are currently in development.
- **The Agave-Human Symbiosis**
Project conceptualization is just beginning and first steps towards collaboration with the Tohono O’odham Nation have been made.

2. Convene transdisciplinary working groups to address priority issues facing the future of life in arid environments

The place-based research described above helps us better understand the diverse dimensions of natural and cultural life in the desert. Yet, solutions to the problems of sustaining life in the desert into the future require transcendent measures that can only be gained by bringing together diverse approaches, theories, methodologies, and skill sets that cannot be possessed by any individual researcher. Diverse groups with complementary perspectives and skills can achieve otherwise inaccessible results in a venue that catalyzes creative interaction, innovation, and long-term collaboration.

The Desert Laboratory on Tumamoc Hill can be that place to spark and incubate ideas in arid lands research. We propose to convene research teams organized as working groups for periods ranging from six months to two years. These research teams will take the next step to investigate how to mitigate and adapt to the problems of sustaining biocultural life in the desert; an essential component of this vision is to develop clear avenues towards implementation and relevancy outside the academic sphere.

The key question these working groups will address is how to sustain life in the desert in the face of climate change and other anthropogenic stressors. This core concept is intentionally left broader than a specific call for proposals. The working group model aims to allow for a bottom-up identification of the timeliest opportunities and challenges, which are guided to inclusive problem solving and a solutions-based outcome by the required proposal criteria (Figure 2 and criteria below). Inclusion of multiple stakeholders and perspectives will ensure real-world problems are addressed and investigated to develop workable solutions.

(2) Transdisciplinary Working Groups

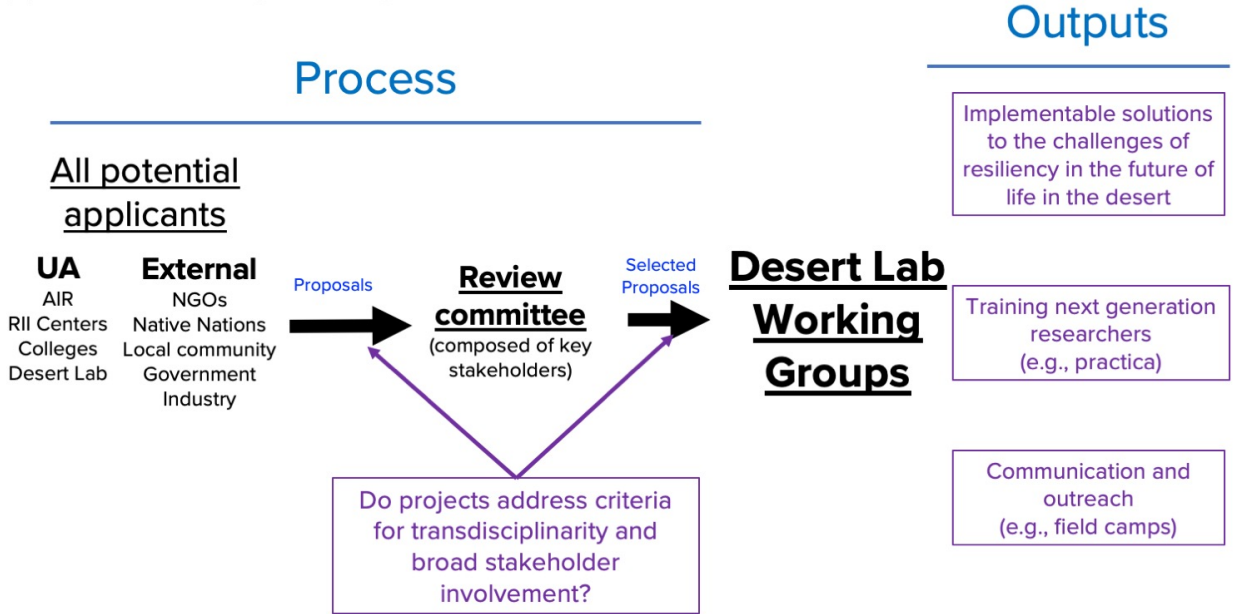


Figure 2. Visualization of the working group application, review, and implementation process.

For example, working groups could develop guidelines for minimum-energy housing based on traditional practices from global desert societies. In this case, a team of Indigenous community groups, anthropologists, historical architects, engineers, and marketing researchers would collaborate with policy makers to design key regulations and strategies to incentivize desert-smart building and homes. A working group could address the critical need to integrate biology and sociology of fisheries and tourism in the Gulf of California. A lack of understanding of the relationship between the social drivers and biological realities has delayed the successful implementation of solutions-based science for decades. Hard lessons have shown that teams need to bridge data and communication gaps to achieve a fisheries model that supports livelihoods and the environmental resource.

Inherent to both examples is that key stakeholders from across the region and diverse sectors would be able to gather and begin to implement a new approach to adaptive management that would allow the communities to proactively address emergent challenges of the future of life in the desert.

Working groups should have ~5–15 members, including researchers, practitioners, and stakeholders. Successful proposals will receive funding for meetings of the group, graduate students or postdoctoral fellows to facilitate the research, logistical support from Desert Lab staff, University computer support, and professional facilitators to foster communication among the diverse perspectives and cultures of the working group participants. Depending on the composition of each group, meetings for intense, collaborative work may be frequent half- or full-day meetings (held at the Lab) or fewer multiday meetings (held at B2 or another local venue), along with video conferencing as needed. In some cases, it would be desirable to provide partial researcher salary as well (e.g., sabbatical release time).

The working groups offer outstanding opportunities to integrate research with education, both within the University and as community outreach. Working groups could develop associated experiential learning courses for members of the public (field camps in Mechanism 3) and University of Arizona undergraduate and graduate students (Mechanism 4). Participants of either group would undertake projects in tandem with working group members to investigate and develop products for some aspects of the proposed research. Similarly, groups of Master's degree students could conduct team projects in lieu of individual theses as part of the research coordinated by the working group. These educational aspects would bridge traditional barriers for community science and across schools and departments of the University and benefit both the research and participant experiences.

We anticipate budgets of \$60,000 to \$80,000 per working group and hope to support a minimum of three, but ideally five or six, working groups functioning simultaneously. Successful proposals will include most or all of the following criteria to create a transdisciplinary approach and broad stakeholder involvement:

- Focus on a problem that addresses a core challenge or opportunity for the future of life in arid environments;
- Have members of the working group from multiple disciplines, e.g., natural sciences or engineering and social sciences or humanities and public policy;

- Have members of the working group who are stakeholders from outside the University of Arizona, e.g., from government agencies, Indigenous communities, local interest groups, and/or industries;
- Involve stakeholders from outside the working group in codevelopment of the research plans;
- Include an educational component such as an interdisciplinary course or master's team project;
- Describe specific mechanisms for communicating results of the research to stakeholders and the public including artistic collaborations and/or on-line products and materials aimed at a broad audience in addition to peer-reviewed articles;
- Include a leadership and management plan to ensure that the proposed research and communication are effectively implemented;
- Link to ongoing research at the Desert Laboratory, AIR, Biosphere 2, or to other regional or UA initiatives.

To ensure that the proposed working groups address problems for the future of life in the desert in a bottom-up manner, an inaugural symposium should be held prior to the launch of the program in which stakeholders discuss their needs for research to inform policies and practices that mitigate the impacts of stresses on linked human and natural systems of the desert. Possible participants include members of academia; community leaders and professionals; tribal leadership, elders, students, and other representatives from Native nations; political leaders; and staff at government agencies.

3. Tumamoc Institute of Science, Culture, and Art

The Tumamoc Institute of Science, Culture, and Art will be an umbrella effort for the Desert Laboratory’s suite of public programs to widely share scientific research, explore diverse stories, and increase cultural understanding, through field explorations, citizen-science investigations, lectures, and art education and installations.

The Institute will be a self-sufficient program that generates revenue through enrollment by members of the public for field camps, field trips, community classroom seminars, and workshops (Figure 3).

(3) Tumamoc Institute of Science, Culture, and Art

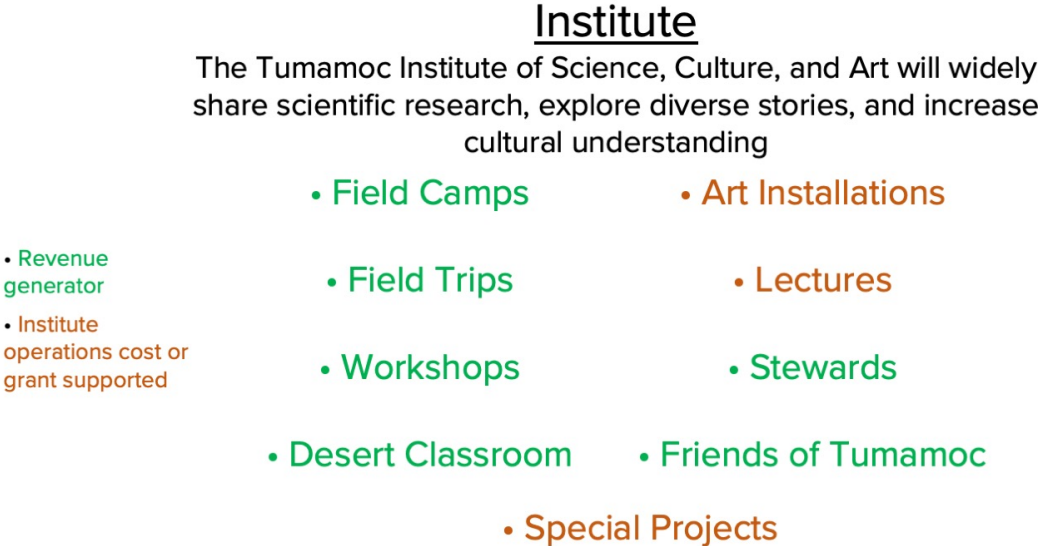


Figure 3. Overview of the Tumamoc Institute of Science, Culture, and Art key components with revenue sources.

Programs include:

- **Field Research Camps**—Field camps are experiential learning opportunities that directly investigate and address through action the priority issues facing the future of life in arid environments. Accordingly, field camp topics will be selected in concert with Tumamoc transdisciplinary working groups (Mechanism 2) and work synergistically to both educate participants and develop solution-driven products of benefit to the working group topic. The field camps are five-day immersive learning experiences that engage paying members of the public in community science. The field camp will be undertaken in a thematically relevant remote location that underscores and directly ties people to the elements being investigated. Participants will engage in real-world problem-solving guided in scientific investigation by a team of experts from the working group. Participants will emerge from the field camp having deeply explored a core ecological and/or cultural challenge and will present their findings to the group and will be

conferred a Tumamoc Field Research Camp commendation. Participation in Field Research Camps will be by application.

The Desert Lab will reserve a portion of the revenue and seek matching funding from donors so that every third year we will host a Field Research Camp for Indigenous researchers in their communities, including the Comcaac, Tohono O’odham, and Yoeme.

- **Field Trips**—From one to 10 days, field trips are exploratory in nature, focusing on sharing a region, often with a tie to Desert Laboratory research and, whenever possible, with local and Indigenous partners as trip leaders. Examples: Trincheras, Sonora, Mexico (three days) with archaeology experts from the U.S. and Sonora; Ancient Agave Roasting Pits of Tumamoc (one day) with Tumamoc archaeology experts; Álamos, Sonora, México (10 days) exploring the biological diversity of the tropical deciduous forest with Nature and Culture International and local guides; Pinacate Biosphere reserve (five days), exploring the geological and ecological marvels of the driest place in North America.

- **Art Workshops**—From one to eight sessions, often grouped over a three-day weekend. Examples include Nature Journaling: Learn the Art of Seeing and Recording the World Around You (three days); Writing the Lives of the Sonoran Desert: Exploring Nature with Words (three days); Drawing Skills for Field Notebooks with guest science speakers (eight days over eight successive Saturdays).

- **Desert Classroom Series**—These seminars will feature subjects related to Tumamoc research, such as archaeology, paleontology, repeat photography, and desert ecology. The seminars will be virtual or in person, taught by Tumamoc and other University staff and researchers, visiting faculty, and other community partners, and may vary between four and 10 weeks, and between two to four hours per week (12–20 hours total per seminar). Some courses will be during the daytime, and others will be in the evening.

- **Art Installations**—By invitation and application, temporary art installations and projects on Tumamoc Hill to connect visitors to a wide range of narratives and themes that often go overlooked when walking the Hill. Examples include: Return of the Gila Topminnow by Kimi Eisele; paper sculpture for the Greenhouse (using old ecological journals that were destined for recycling) by Nick Georgiou; Sonoran Strange spoken poetry by Logan Phillips and Adam Cooper Teran as part of the Tumamoc Tour app; aerosol murals forthcoming by the Indigenous arts cooperative Neoglyphix. Projects are managed and convened by the Tumamoc Arts Working Group.

- **Lectures**—Presented in series format in fall and spring, the Tumamoc lectures explore a theme relevant to the mission and future of the Desert Laboratory in monthly lectures over the course of a semester, with expert speakers from throughout the Southwestern U.S. and northern Mexico.

- **Special Projects**: Include diverse activities such as Cuéntame Más: Tales from Tumamoc, which highlights the diversity of the Hill’s visitors and neighbors through story-gathering and -sharing.

4. Undergraduate and graduate education courses on the future of life in the desert

The Desert laboratory has been a hub for training and education since becoming part of the University of Arizona. Classes and field trips by Paul Martin in the Desert Lab Library (ca. 1970–1990) on topics from Pleistocene megafaunal extinctions to the diversity of the northern tropics are legendary. It is essential that the research of the Lab continue to be both instilled in and contributed to by University students.

The University of Arizona is a leader in the environment. Course offerings from the Desert Lab in partnership with units like RII’s Arizona Institutes for Resilience (AIR), the Southwest Center in the College of Social and Behavioral Sciences, as well as other departments and colleges would be strong additions to complement critical curricula in global change that also help establish a sense of place among the student body (Figure 4).

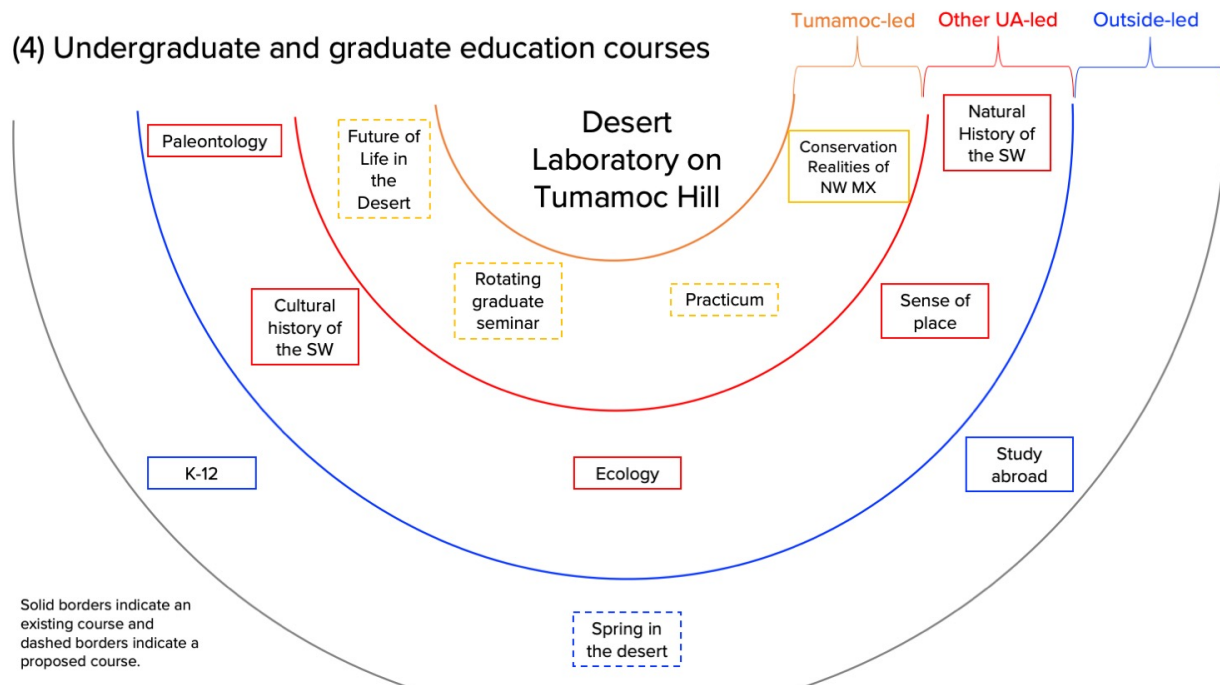


Figure 4. Different tiers of the undergraduate and graduate courses based at the Desert Laboratory, with examples of offerings led by the Desert Lab, other University of Arizona units, and non-University of Arizona entities.

Course offerings could include:

- **One-unit introductory undergraduate course, The Future of Life in the Desert.** Through the lens of social and scientific applications, 50–100 students will explore the past, present, and future of the culture and ecology of the Sonoran Desert using real-world studies and examples from the Desert Laboratory and the desert at large. Emphasis will be on how past and present

understandings and lessons learned in the Sonoran Desert region can be used to identify climate vulnerabilities and inform future strategies, translatable to other arid regions of the world. Lectures will cover a range of topics that embody the biocultural themes of the Desert Laboratory (culture, ecological change through long-term observations, paleontology, food resilience, climatic change, and human survival in increasingly arid environments). Students will learn through experiential-based learning in one of these topics and then practice science communication by sharing what they learned with walkers on Tumamoc Hill toward the end of the semester.

- **Graduate seminar.** A standing graduate seminar on rotating topics led by Desert Lab researchers, both permanent and visiting. These in-depth study groups will provide a space for students across campus to learn and share perspectives on timely topics pursuant to the mission and focus of the Desert Lab.

- **Undergraduate and Graduate Transdisciplinary Working Group Practica.** As described above in Mechanism 2, the working group projects convened and supported by the Desert Laboratory would benefit from project development by student groups. This practical, solutions-based course framework would provide students with an exceptional applied learning environment. The practicum theme would change based on the working group topic and allow partnership with a diversity of courses, departments, and colleges across campus.

C. Relevance to University Strategic Plan

This scientific and education vision for the Desert Laboratory comes at an important time for the University and the Lab itself. After more than 50 years in the College of Science, the Desert Lab is now one of the centers and institutes overseen by Research Innovation and Impact as a part of the Arizona Institutes for Resilience (AIR). With a renewed ability to connect across campus and in the context of President Robbin's University-wide strategic plan, even given delays in implementation, now is the optimal time to establish the partnerships that will allow the Desert Lab's vision to flourish. We envisage several specific linkages:

Pillar 1: The Wildcat Journey

Tumamoc Hill is a part of the University of Arizona campus. Students need more opportunities to connect to the world around them and gain hands-on experiences. Tumamoc Hill can be a unique and transformative learning space that can be a touchstone through their wildcat journey (1.3B).

Pillar 2: Grand Challenges

The majority of the Desert Lab's scientific vision focuses on the associated grand challenges for life with climate change in arid environments. With partners across campus, the Desert Laboratory on Tumamoc Hill can maintain the University's prominence in environmental science (2.2A).

Pillar 3: The Arizona Advantage

The Desert Laboratory is in many ways defined by its sense of place. That entails an explicit partnership with the region's Native Nations and institutions, and with collaborators and communities in Mexico. Several facets of the strategic plan play to these strengths (3.1C1, 3.3C1, and 3.3C2).

Pillar 4: Arizona Global

Experience-based learning transforms student lives. Through an existing study abroad course, public field excursions, and numerous collaborations across the region and arid lands globally, the Desert Lab can become a leader with other partners on campus in study abroad experiences in arid lands (4.3A2).

Pillar 5: Institutional Excellence

The potential and opportunities of the Desert Lab are significant. Likewise, investment in existing infrastructure (e.g., early 1900s houses at the base of Tumamoc Hill, the National Historic Landmark Laboratory buildings, and irreplaceable paleoecological collections) are needed to maintain the excellence of the site for the next 115 years (5.5B).

D. Existing and proposed partnerships to address the future of life in the desert

Consortium for Arizona-Mexico Arid Environments (CAZMEX)

The Consortium for Arizona-Mexico Arid Environments is a binational funding program between the Mexican Federal Commission for Science and Technology (CONACYT) and the University of Arizona. Since its inception, CAZMEX provides support to binational teams of researchers to contribute to the consolidation of the scientific, technological and innovative capacities of the region, relative to the environment and climate change in the arid and semi-arid zones of Mexico and the United States in environmental sustainability and social justice. There is an incredible opportunity to link the CAZMEX program with the working group convener mechanism described above.

The Agnese Nelms Haury Program in Environment and Social Justice

Since 2015, the Haury Program has established itself as a critical funder of people working to protect our planet and ensure justice for those who inhabit it, with particular focus in the greater Southwest. The Haury Program's focus on the Navajo Nation for the next five-year period is a paradigm change to help address systemic inequalities and grand challenges, especially in the arenas of food and water. The efforts of the Desert Lab in the recognition of the cultural importance of Tumamoc Hill and the need for healing and proactive collaborations align well with this new focus. Opportunities for collaborations and partnership between the Desert Lab and the Haury Program is strengthened by the inclusion of both programs within AIR.

RII Research Advancement Grant Program

Research Innovation and Impact provides critical jump-start, seed, team, and scientific capacity support. Drawing on the vast capacity of talent in desert environments across the entirety of the University of Arizona, a focus could be added to support the working group model and expand current efforts into larger transdisciplinary projects and teams.

E. Need and Implementation

1. Increase support for place-based field research

Need:

- Personnel: \$30,000
Director of research to lead grant writing.
- Operations: \$100,000
Annual support for research-related costs, including incentivization support in the form of invoiced subcontract work for currently unfunded Designated Campus Colleagues (DCCs) undertaking the majority of this effort.

Implementation:

Projects run the gradient from already funded to proposal generation stage. New proposal generation and successful grants will be increasingly hard to attain without a modest investment in personnel that would lead to a return on investment.

2. Convene transdisciplinary working groups

Need:

- Working group grants: \$240,000
Three working group grants per year at \$80,000 per project
- Personnel: \$20,000
Contract transdisciplinary facilitator

Implementation:

This new initiative needs to be jump started with new investment from the University (RII, Central Administration) and private philanthropy.

3. Tumamoc Institute of Science, Culture, and Art

Need:

- Infrastructure improvements: \$25,000
Initial investment in facilities (lighting and technology in Desert Lab classroom space) and technology for virtual class offerings (high-quality video camera for recording lectures and demonstrations, sound equipment, studio modifications).

Implementation:

Once initial investment is made, this is a self-supporting program based on revenue from the Desert Classroom, field camps, field trips, workshops, grants, etc.

4. Undergraduate and graduate education courses

Need:

- Adjunct Professor: \$20,000
Annual course instruction of The Future of Life in the Desert

Implementation:

A new initiative that needs direct support and linkages with other teaching units.

F. Appendices

- Appendix 1. Accomplishments of the Desert Laboratory on Tumamoc Hill since Benjamin T. Wilder became Director, October 2016.
- Appendix 2. Place-based field research of the Desert Laboratory on Tumamoc Hill.
- Appendix 3. Desert Laboratory organizational and strategic plan chart.

Appendix 1. Accomplishments of the Desert Laboratory on Tumamoc Hill since Benjamin T. Wilder became Director, October 2016.

Funded Research Projects

- Collaborative Research: Testing evolutionary pseudocongruence along the Baja California peninsula through integration of geologic and genomic data
Research project on the flora and geogenomics (testing geologic hypothesis with genetic datasets) of the Baja California Peninsula.
2019–2024. Supported through an NSF Frontier Research in Earth Sciences grant for \$2.6 M (\$694,000 UA).
- The Future of the Saguaro and long-term data in the Sonoran Desert
Effort to establish the saguaro as a model system to understand climate change in arid environments.
2020–2021. Supported through U.S. National park Service grant, \$75,000.
- Marine subsidies produce cactus forest on desert island
Research project on the pathway of nutrients from the sea to the land on islands in the Gulf of California.
2017–2019. Supported through Haury Faculty Fellowship, \$76,000.
- Amphitropical disjuncts and the Monte Desert
Exploratory trip to the Monte Desert of Argentina to establish research and collaborations to better understand the biogeographic history and shared species between the Sonoran and Monte deserts.
2017–2019. Supported through Haury Faculty Fellowship, \$76,000.
- Hidden Water: Fresh water pozos of the Gran Desierto
The age and origin of fresh water springs on the edge of the Gran Desierto, the largest sand sea in North America, were determined to shed light on an ancient aquifer and the history of the Colorado River.
2016–2018. Supported through U.S. National Park Service grant, \$50,000.
- Cuentame Más: Tales from Tumamoc
Oral story project to understand people’s connection to Tumamoc Hill.
2018–2019. Supported through a Centre National de la Recherche Scientifique (CNRS) grant, € 5,000.
- A Living Laboratory: Forging Connection Between UA Students and Tumamoc Hill to Monitor the Pulse of the Desert
Student led research to monitor the wildlife biodiversity of Tumamoc Hill.
2018–2019. Supported by the University of Arizona Green Fund \$23,625.

Research Community

Increased Desert Laboratory research community from three individuals in 2016 to over 20 through a mixture of Designated Campus Colleagues, faculty from multiple colleges, students, and emeritus researchers.

<https://tumamoc.arizona.edu/people>

Tumamoc Hill Advisory Council

Established the Tumamoc Hill Advisory Council, chaired by Russell Long, in 2016. An esteemed group of over 10 individuals from the University of Arizona, Tucson community, and international scientific community that advises on future directions of the Desert Laboratory.

<https://tumamoc.arizona.edu/tumamoc-hill-advisory-council>

Mentoring and Teaching by Dr. Wilder

Doctoral Candidates

- 2019. Lucila Armenta, Centro de Investigación en Alimentación y Desarrollo, A.C., (CIAD) Unidad Guaymas.
- 2018. Hector Zamora, Geosciences, University of Arizona

Undergraduate Students

- 2019. Mandy Becker, Ecology and Evolutionary Biology, University of Arizona

Teaching

- Led the inaugural offering of the transdisciplinary Study Abroad Course, “Conservation Realities in Northern Mexico” over the summer of 2018.

Publications

- *Proceedings of the Desert Laboratory*
Established the new open access scientific journal, *The Proceedings of the Desert Laboratory* (<http://tumamoc.arizona.edu/proceedings-desert-lab>) with the following contributions:
 - 1. Felger, R.S., S.D. Carnahan, J.J. Sánchez-Escalante. 2017. Oasis at the Desert Edge: Flora of Cañón del Nacapule, Sonora, Mexico. *Proceedings of the Desert Laboratory*, Contribution No. 1:1–220.
 - 2. Esquer, G. 2018. Campos de Fuego: A Brief and Fantastic History of an Expedition into the Volcanic Region of the Pinacate. English and Spanish Editions. *Proceedings of the Desert Laboratory*, Contribution No. 2:1–154.
 - 3. Brid, W.L. 2020. In the Arms of Saguaros: Iconography of the Giant Cactus. *Proceedings of the Desert Laboratory*, Contribution No. 3.
- Special Publications of the Desert Laboratory. Stand-alone books published by the Desert Laboratory:

- Felger, R.S., S.D. Carnahan, J.J. Sánchez-Escalante. 2020. *The Desert Edge: Flora of Guaymas-Yaqui Region of Sonora, Mexico*. Special Publication of the Desert Laboratory.
- Felger, R.S. and F.S. Molina. 2020. *Plants & Animals in the Yoeme World: Ethnoecology of the Yaquis of Sonoran and Arizona*. Special Publication of the Desert Laboratory.
- Over 20 peer reviewed scientific articles (<http://tumamoc.arizona.edu/research/bibliography>), including:
 - Ge, X. M., J. P. Scholl, U. Basinger, T. E. Huxman, D. L. Venable. 2019. Functional trait trade-off and species abundance: insights from a multi-decadal study. *Ecology Letters* 22:583–592.
 - Rodríguez-Buriticá, S., D. E. Winkler, R. H. Webb, D. L. Venable. 2019. Local temporal trajectories explain population-level responses to climate change in saguaro (*Carnegiea gigantea*). *Ecosphere* 10:e02844. <http://dx.doi.org/10.1002/ecs2.2844>.
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Infrastructure Improvements and Resource Management

- Repaved Tumamoc Hill road, 2018
Reached the \$200,000 project cost through University of Arizona central administration (\$100,000), philanthropic challenge gift (\$50,000), and crowdfunding campaign with over 260 donors (\$50,000).
- Renovation and improvement of the Vertebrate Paleontology fossil collection, 2018–2020.
Reestablished this previously abandoned and invaluable natural history collection with support from the University of Arizona Water, Environmental, and Energy Solutions (WEES)-TRIF Equipment Grant (\$88,404), the Southwestern Foundation for Education and Historical Preservation (\$10,000), and the curatorial leadership of Dr. Jeffery Saunders, Dr. Jessica Harrison, and Dr. Everett Lindsey.

- Deferred maintenance of Desert Laboratory potable water and waste water, 2020
After decades of decay, University of Arizona Facilities Management is leading the replacement of the Lab's original 1900s piping, under the on-site guidance of Director of Operations Clark Reddin (\$200,000).
- Rebuilt the historic Desert Laboratory Greenhouse, 2017–2019
Working with multiple stakeholders, renovated the original 1906 greenhouse, a part of the National Historic Landmark listing with support from the U.S. National Park Service, Heritage Partnerships Program (\$10,000), the University of Arizona College of Science (\$20,000) and a philanthropic gift (\$20,000).
- Improvement of the Desert Laboratory Library and Map Room, 2017–2020
Reactivation and curation of the historic Desert Laboratory library and adjacent archival map room with support from the Southwestern Foundation for Education and Historical Preservation (\$16,000) and five University of Arizona Master of Library Science interns.
- Development of master plan for Tumamoc Hill Visitor Center, 2018–2020
In concert with the Tumamoc Hill Advisory Committee, The University of Arizona College of Architecture, Planning and Landscape Architecture, and BWS Architects, developed a master plan for a new visitor center at the base of Tumamoc Hill (\$36,475).
- Establishment of multiple desert gardens:
 - Native pollinator garden at the Luminous Mother Shrine at the base of Tumamoc Hill, in collaboration with Tucson Audubon and Manzo Elementary.
 - Tumamoc Agave Heritage Garden with support from Hotel Congress, the Kellogg Foundation, and the Agnese Nelms Haury Program (\$5,000).
 - Re-established the Sonoran Plant garden and original 1906 rainwater harvesting system at the Desert Lab with support from the Agnese Nelms Haury Program (\$21,000).
- Re-initiated Buffelgrass control on Tumamoc Hill 2016–2020.
First active control efforts since ca. 2010, done in partnership with Arizona Sonora Desert Museum, Pima County, and National Park Service with support from the Arizona Department of Forestry and Fire Management (2018, \$20,000; 2020–2021, \$105,000).

Community Outreach

- Developed the Tumamoc Tour, 2016–2017
Bilingual mobile app that provides an orientation to Tumamoc Hill. Supported by the University of Arizona College of Science, Visit Tucson, Pima County, Ventana Medical, Arizona Daily Star, TEP, Holualoa (\$67,000).

- Developed and improved relations with Indigenous stakeholders (2017–2020)
Tumamoc Hill is a site of profound significance for the Native Nations of the greater Southwest, especially the Tohono O’odham. Relationships and reciprocal discourse has been established to increase the agency and connection Native nations have to Tumamoc Hill, an effort that was greatly supported by the addition of Program Coordinator Dr. Anna Seiferle-Valencia to the Desert Laboratory staff in 2019.
- Established Friends of Tumamoc, 2019–2020.
As part of the repaving of the Tumamoc Hill road and crowdfund campaign, launched the Friends of Tumamoc. Since the first of January 2019, 344 people have become friends and given \$83,159.
- Established Tumamoc Stewards, 2020.
To better maintain the integrity and communicate the richness of Tumamoc Hill, established the Tumamoc Stewards volunteer effort with 30 inaugural stewards.
- Led international field trips for the public, 2018 and 2020.
The Desert Laboratory research community led a public group to the Pinacate Biosphere Reserve and Trincheras archaeological site, both in Sonora, Mexico.
- Participated in the Border BioBlitz, March 2018 and 2019.
A community science effort along the U.S.-Mexico border with 11 teams from the U.S. and Mexico and over 100 participants that recorded 1,000 species.
- Increased media attention, 2016–2020.
The Desert Laboratory has been featured in over 30 popular articles, including multiple front-page articles in the Arizona Daily Star, and featured in the New York Times, and other regional and national outlets.
- Seasonal lecture series, with the following themes and an average at capacity audience of over 90 people, 2017–2020:
 - Spring 2017, Fall 2017, and Spring 2018: various Sonoran Desert science and conservation presentations.
 - Fall 2018: Campos de Fuego–Explorations of the Pinacate Volcanic Range.
 - Spring 2019: La Vaquita Marina–The World’s Most Endangered Marine Mammal. Where do we go from here? *In collaboration with CEDO.*
 - Fall 2019: New Explorations of the Río Mayo. *In collaboration with the Southwest Center.*
 - Spring 2020: The Cultural Landscape of Cemamagi Du’ag.

Art and Science Program

Established the Tumamoc Art and Science program (<http://tumamoc.arizona.edu/art-and-science>) with the following elements:

- Tumamoc Transdisciplinary Arts Working Group, 2018–2020.
A diverse group of artists and creators from the larger Tucson community working to explore, document, and share the stories and richness of Tumamoc Hill in new and meaningful ways that connect art, science, and community. Supported by the University of Arizona Confluentcenter (\$15,000).
<http://tumamoc.arizona.edu/tumamoc-arts-working-group>
- Initiated the Tumamoc Arts Fellow
 - Lyn Hart, Arts Fellow, 2018
 - Roseann Hanson, Arts Program Coordinator, 2019–2020.
- Creation of a set of public workshop offerings:
 - Observational Drawing Skills for Field Note Books
(<http://tumamoc.arizona.edu/art-and-science/course>)
 - Writing the Lives of the Sonoran Desert
 - Nature Journaling
- Support of Desert Laboratory Artist in Residence, Paul Mirocha and the development of the website Tumamoc Sketchbook (<https://tumamocsketchbook.com/>)

Appendix 2. Place-based field research of the Desert Laboratory on Tumamoc Hill.

- **The Shifting Boundaries of the Sonoran Desert**

Researcher and early Director of the Desert Lab, Forest Shreve, defined the Sonoran Desert and its subregions based on his knowledge of plants and places. Yet questions remain: how did the desert change over geological time, what is the imprint of those changes on modern day diversity, and how will this change in the future? Using the emerging field of geogenomics, recently funded collaborative research is resolving longstanding biogeographic puzzles of the Sonoran Desert, such as whether current disjunct distributions of species represent locations where the desert survived through the wetter Pleistocene. This synthetic understanding will help define how populations are responding to climate change today, both through genetic evolution and spatial movement, and help forecast future trajectories.

Currently supported, 2019–2024, \$2.6M Collaborative NSF grant with University of Oregon, Arizona State University, and California State Sacramento.

- **Tumamoc Arts Working Group**

The mission of the transdisciplinary Tumamoc arts working group is to explore, document, and share the stories and richness of Tumamoc Hill in new and meaningful ways that connect art, science, and community. The working group collaborates in incorporating the diverse perspectives and themes encapsulated by Tumamoc Hill. Rather than undertaking this work in isolation, it is essential for the Lab to connect to diverse ways of seeing this space and the work that can be done here. The working group explores innovative ideas that meld art and science via the canvas of Tumamoc Hill to enrich the narratives created and their meaning in our community. The roles of the working group can be expressed in three overarching themes: visionary, advisory, and advocacy.

With support from the UArizona Confluentcenter (\$15,000, 2018–2020) the working group was established in 2018, consists of 15 individuals, and is actively undertaking its first project. More information available here: <https://tumamoc.arizona.edu/tumamoc-arts-working-group>

- **Buffelgrass and the Anthropocene**

One of the greatest potential agents of change in the Sonoran Desert is the exotic species buffelgrass. It has the capacity to transform the desert to a grassland by outcompeting native plant species and spawning a fire regime native species cannot withstand. Tumamoc Hill is in the crosshairs of this harbinger of the Anthropocene with dense infestations on over 190 of the 860 acres of the reserve. An ongoing program of control and restoration with the Arizona-Sonoran Desert Museum and the College of Agriculture and Life Sciences, in coordination with research on ecosystem effects of invasion, is helping to provide a model of how to

realistically manage the great reshuffling of arid land communities due to climate change.

Currently supported, 2020–2021, \$105,000 grant with Arizona-Sonoran Desert Museum and active restoration research by the Gornish Lab in the College of Agriculture and Life Sciences.

- **Tracking the Pulse of the Desert**

The Desert Lab’s perennial plots are the longest running population studies in the world. They have yielded unique data on the local dynamics of desert plants and their responses to environmental change. They alone, however, are not comprehensive enough to allow meaningful understanding of regional change. Collaboration with entities such as Saguaro National Park and the use of drones and remote sensing with machine learning will expand and automate future data collection. The next steps of the Desert Lab’s long-term plots are to build a century of monitoring vegetation change at the Desert Lab up to a regional scale. This research will yield needed regional understanding of the shifting nature of the desert in an era of climate change.

Currently supported, 2020–2021 with a grant from the National Park Service. The effort is in collaboration with Saguaro National Park and with an Ike Russell postdoctoral scholar to be brought on board in summer 2020.

- **Human and Paleoenvironmental History of the Arid Core of the Sonoran Desert**

The 2019 discovery of a new Clovis site with extinct megafauna by Desert Laboratory staff in the arid heart of the Sonoran Desert in the Gran Desierto de Altar is exceptionally exciting because this area is hypothesized to be the refuge for Sonoran Desert vegetation during the ice ages. What was the climate, vegetation, and animal ecosystem in the heart of the Sonoran Desert at the end of the Pleistocene? How did bands of the earliest widespread culture in the New World adapt to this region and what were their connections to the Gulf of California coast and other ecozones? Was the extinction or local disappearance of megafauna caused by climate changes, human over-predation, or a combination? Investigation of this and other sites in the Gran Desierto will shed light on these long-standing questions and allow new understandings of ecosystem shifts and early human adaptations in the heart of the Sonoran Desert.

Developing grant proposals at present for this recent discovery.

- **Aridamerica Food Resilience**

Accelerating climate change and water scarcity have begun to disrupt, degrade, and restructure arable lands and food systems in the deserts of North America. Tucson and southern Arizona, however, are surrounded by diverse wild food plants adapted to arid environments that have long been utilized by multiple traditional knowledge bases. The Desert Lab will work with campus, community, and Indigenous partners, as well as government, on two related projects that

incorporate these natural and cultural resources. The first is an assessment of the southern Arizona food system to identify ways to increase the sustainability and resilience of the region's food provisioning system in adaptation to climate change and other trending pressures. The second is a five-year initiative to prototype a radically different form of desert food production that establish resiliency in the face of dramatic disruptions, create jobs, and help urban communities adapt to accelerating climate change over the next half century.

Developing grant and foundation proposals with Dr. Gary Nabhan and B2.

- **Hindsight: Using the Lens of Repeat Photography with Community Science to Track Change across the Landscape**

When we critically reflect on past events, clarity arises. Yet, the past is often mysterious or unseen. Tens of thousands of landscape images taken since the advent of modern photography provide a baseline of environmental patterns. This effort was developed into a science by Desert Laboratory scientists Dr. Raymond Turner and Dr. James Rodney Hastings. The act of matching historic images with today's view provides a direct measure of change at the regional scale. One image can tell a thousand words; one million can change the way we see the world. Through an open platform that engages community scientists to contribute their photographs and join the hunt for the perfect match, a massive database can be built. Calibrated by professional scientists, crowdsourcing techniques, and trained AI imaging software, we can activate thousands of lenses across the landscape to detect patterns of change in real time.

Collaboration with the United States Geological Survey has been initiated and grant proposals are currently in development.

- **The Agave-Human Symbiosis**

"The uses of agave are as many as the arts of man have found it convenient to devise." These words of Howard Scott Gentry point to the long-standing connection between people and the agave, a remarkable North and South America arid land plant. This connection is a fundamental part of the cultural landscape of Tumamoc Hill. The northwest portion of the Lab property is an ancient cultivated agave field where Hohokam people enhanced the landscape to direct water to rockpiles upon which the plants were grown. Today, the rock piles are barren: the plants have disappeared in the absence of human care. Knowledge of how to live in the desert exists on this landscape and in the traditional ecological knowledge of the Tohono O'odham, other Native nations, and Western science. These approaches are complementary and can provide synthetic insights about how this system of rock piles and human care allowed agave to thrive. Do rockpiles facilitate symbioses between plants and soil microbes? Has agave evolution been modified by human selection, shaping modern diversity? Working together, we can renew and advance our knowledge of how to live in a hot and dry world.

Project conceptualization is just beginning and first steps towards collaboration with the Tohono O'odham have been made.

Appendix 3. Desert Laboratory organizational and strategic plan chart.

