Expansion of Biology 47 and the associated research activities from Jasper Ridge to the Dish area

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October 20, 2021

Biology 47, Introduction to Research in Ecology and Evolutionary Biology, is one of the core foundational courses offered to a large number of undergraduate students at Stanford. The course is required for all Biology majors and is also taken by many students of various other majors, from Human Biology to Earth Systems to Mechanical Engineering. This document describes a proposed plan to expand this course from the current site, Jasper Ridge Biological Preserve (JRBP), to a new site, the Dish area. This expansion is necessitated by the Searsville Watershed Restoration Project due to happen in the near future at JRBP, which will prevent us from accessing the current field site there over multiple years once the project starts. In the meantime, Biology 47 and the research associated with the class will use the Dish hill. Once the Searsville Dam construction is finished, we will use our study plants at both JRBP and the Dish hill for teaching and research.

1. Brief history of Biology 47

A comprehensive assessment of the Department of Biology's undergraduate curriculum was conducted in 2005-2007 by the H&S curriculum committee. The curriculum received high marks for the advanced courses, the research opportunities offered to students, and the introductory lecture series, but the two-course introductory laboratory series was considered less than adequate according to student evaluations. The Department was perceived as having the potential for improvement, particularly if the research conducted by the faculty could be taken advantage of for integrated curriculum. After this assessment, the Department decided to make major financial and logistical investments into a reform of the laboratory series: Biology 44X (currently Biology 45), on cellular and molecular biology, and Biology 44Y (currently Biology 47), on ecology and evolutionary biology. The goal was to develop inquiry-based courses in which students identify and work on open-ended, authentic research questions. The intention was to design a course that is directly built on specific research efforts by the faculty.

The Biology Department invested heavily in planning, developing, and testing the new course. In 2009, initial exploration and preliminary research in preparation for a new Biology 47 was conducted at JRBP by the faculty and the graduate and undergraduate students who assisted the faculty. In 2010 and 2011, a new lab was developed and offered as a pilot version. In 2010, two sections of 10 students each (volunteers) took the pilot version, while the rest of the students taking this series (about 100 students) took the previous version of the course. In 2011, we expanded the pilot version to four sections. Concurrent offering of the new and old versions allowed student learning to be directly compared. The

Biology 47 students at Jasper Ridge (photo by Nona Chiariello)

old version of 44Y consisted of 2-week modules on the topics of ecology, immunology, cell biology, and animal behavior. These were cookbook-style labs, where students mostly just followed steps outlined in lab manuals. In 2012, the new 44Y course completely replaced the older version, and its annual offering has continued to date. The latest implementation of this class in Spring 2021 involved 4 instructors and 4 TAs (taught online, using the data that Biology 47 students from previous years collected).

The redesigned Biology 47 has been a major success. The value of the innovative inquiry-based teaching that this class has offered over the past decade has been widely recognized both within Stanford and internationally:

- *Science* Prize goes to undergrad course that incorporates faculty research
  By Michaela Jarvis, AAAS press release, April 3, 2013

- Stanford researchers study the relationship between nectar microbiomes and pollination
  By Taylor Kubota, Stanford News article, September 11, 2017

- Stanford virtual classroom: fieldwork at home
  By Farrin Abbott, Stanford New video, May 15, 2020

The success of the course has come not only from the Department's commitment, but also from the unique field site and support infrastructure that JRBP has provided to facilitate this course that emphasizes field biology.

The course uses wild plants found along trails (all handicap-accessible) of approximately 2 km in total length at JRBP. Most of these trails are located close to the Searsville Dam, and it will not be possible to continue the course once the Searsville Watershed Restoration Project starts. The class will need to be relocated elsewhere, and given the size of the class, a careful planning and coordination are necessary for the relocation.

2. Investment that has gone into Biology 47

The investment that went into developing and testing the design of the reformed Biology 44Y/47 course include the funding for the personnel listed below, which was invested over and above the normal cost required to run other courses in the Biology Department:

- Two PhD students who each worked for two full quarters in 2009 and 2010 as TAs (Melinda Belisle and Diamantis Sellis)

- An undergraduate student who worked full-time in summer 2012 to conduct a research project that provided data needed to improve Biology 44Y (Ashley Good)

- A full-time course coordinator who worked with the faculty to develop and implement the pilot Biology 44Y course from 2009 to 2015 (Patricia Seawell)

- A full-time lecturer, a position created to maintain the high level of expertise needed for Biology 47 (Matt Knope, 2014-2015; Jes Coyle, 2016-2017; Jesse Miller, 2018-present)

3. Teaching and research impact of Biology 47

In total, more than 900 undergraduate students have taken the course, which was taught every year since 2009. As mentioned above, the teaching impact of the course has been recognized campus-wide and internationally.

In addition, the class resulted in five peer-reviewed publications on the findings regarding the effectiveness of the inquiry-based instruction that was implemented in the course. This educational research was conducted in collaboration with Professor Richard Shavelson at the Graduate School of Education and then graduate students Matthew Kloser and Sara Brownell. We have also published 17 peer-reviewed papers on the research findings that resulted from the course and the associated research activities conducted by the Biology Department faculty and their students and postdocs. All these papers have been highly cited, showing the broad impact that the course has had, in both education and biology.

The course was also a central component of two research grants, which funded continuation and expansion of the Biology 47 teaching and the associated research: an NSF CAREER grant (award number: 1149600) and an NSF Dimensions of Biodiversity grant (award number: 1737758).

We expect that support from the university for relocation of the course to the Dish area will lead to similar successful securing of external funds from the NSF and other agencies.

Anna's hummingbird at Jasper Ridge (photo by Dan Quinn)

4. Proposed plan

Through discussion with Alan Launer (Associate Director of the Stanford Conservation Program), Esther Cole Adelsheim (Conservation Program Manager of the Stanford Conservation Program), and Nona Chiariello (Staff Scientist at JRBP), we have identified the Dish hill as an appropriate location for this relocation.

We propose to establish and maintain a total of 32 patches of the two plant species that the Biology 47 students have used at JRBP over the past decade: 16 patches of sticky monkeyflower, *Diplacus* (*Mimulus*) *aurantiacus*, and 16 patches of yerba santa, *Eriodictyon californicum*. These plants have served as an ideal study system for the students to design and conduct projects regarding the complex ecological and evolutionary relationships between the plants, the pollinators that visit the plants, such as Anna's hummingbird, *Calypte anna*, and the variable checkerspot butterfly, *Euphydryas chalcedona*, and the microorganisms that colonize the floral nectar of the plants via the pollinators, including bacteria and yeasts. The biological knowledge we have gained through the teaching of Biology 44Y and 47 at JRBP

Sticky monkeyflower at Jasper Ridge (photo by Tadashi Fukami)

over the past 10 years will serve as a scientific basis for the future students of Biology 47 to conduct well-informed novel research at the Dish area.

Both plant species, as well as the associated pollinators and microorganisms, are native to California, commonly found at JRBP, and must have been historically abundant in the Dish area as well. Currently, however, very few of these plants are found in the Dish area due to land conversion, cattle grazing, and other human disturbances. Similarly, the checkerspot butterfly, which is also common at JRBP, has very rarely been observed in the Dish area, most likely because of these disturbances. We plan to create 32 patches of these plants (16 patches of each of the two plants), each consisting of 24-32 plants, evenly spaced with each patch 200 m away from the nearest neighbor patch. The study plants are perennial shrubs that live for years. Once established after the initial 2-3 years of planting and maintenance, this "biological infrastructure" will remain in place naturally from one year to the next. In the future, we plan to re-introduce checkerspot butterflies to the area where we do this planting. The butterfly larvae use the bush monkeyflower, and the adults forage on the floral nectar of the yerba santa. We expect hummingbirds and microorganisms to return to the Dish area by themselves once the plants are reintroduced.

Nectar yeast from Jasper Ridge (photo by Manpreet Dhami et al.)

5. Benefits expected from expansion to the Dish area

These plant and butterfly reintroduction efforts will offer the students an exciting rare opportunity to experimentally study how a broad range of organisms, involving plants, animals, and microorganisms, are affected by one another in a complex web of biological interactions in the ecosystem they belong to. The experimental manipulation of the ecological landscape through carefully designed planting at the scale we envision for this course is unprecedented, at least for undergraduate education, and this effort will enable continuation of the mutual benefits that have been possible between the teaching of this undergraduate course and the research conducted by the faculty that teach the course and the graduate students and postdocs who work with the faculty (see Fukami 2013. Integrating inquiry-based teaching with faculty research. *Science* 339: 1536-1537).

Variable checkerspot at Jasper Ridge (photo by Tadashi Fukami)

In addition, the research setting at the Dish will provide a unique opportunity for the students to learn ecosystem restoration as a scientific topic first-hand. For example, the time course over which hummingbirds and the associated nectar-colonizing microorganisms "discover" the plant patches is something we will be able to observe. Ecosystem restoration is a long-standing challenge, and has become a particularly prominent topic not just

biologically, but societally, as recognized by the United Nation's recent declaration of 2021-2030 as the UN Decade on Ecosystem Restoration.

Biology 44Y and 47 have involved transportation of the students and the teaching staff from the main campus to Jasper Ridge, four to five times (to accommodate four to five sections, each consisting of a small number of students to ensure close interactions with the teachers) each week for a total of 6 weeks during the Spring quarter the class is taught. This is a total of 24 to 30 round-trips by bus (typically the bus waits at Jasper Ridge while students are there). It takes about 20 minutes one way, taking up 40 minutes of the class time just for transportation. The Dish area is close to the main campus, and the students would be able to come by themselves by bicycle or using an existing Marguerite line that runs regularly. We will be able to use the saved travel time for more direct on-site learning.

Student volunteers planting monkeyflower seedlings on January 17, 2020 (photo by Haas Center)

Another benefit that comes from having the Dish as a study site is that the teaching, research, and restoration projects that will ensue will be quite visible to the many people who come to the Dish area for recreational purposes, and will therefore be widely known to the general public, resulting in significant outreach and a demonstration of good land stewardship by Stanford.

Finally, the Dish site will allow us to have both restored (Dish) and undisturbed (JRBP) study systems. Once the Searsville Watershed Restoration Project is completed, we will use both the Dish and JRBP for teaching and research. Having both sites will provide us with a wider range of possible approaches than either alone can.

6. Pilot effort in 2020-2021

On January 12, 2020, we planted 65 monkeyflower (*D. aurantiacus*) seedlings for pilot planting at one site (site M01 on the map below). Stanford's Haas Center for Public Service invited Magic, the local non-profit organization we work with for the project at the Dish, to make this planting a service event for Stanford student volunteers. Many students and other volunteers came to participate. Subsequently, Magic watered the plants weekly from February 22, 2020 to December 3, 2020 (with some gaps in March and April owing to pandemic-associated restrictions). Although the seedlings used for the planting were initially small (about 20 cm or shorter aboveground), many of the plants grew well and started blooming by May 2020. Data collected on July 10, 2020 showed that 49 of the 65 plants were still alive and had a total

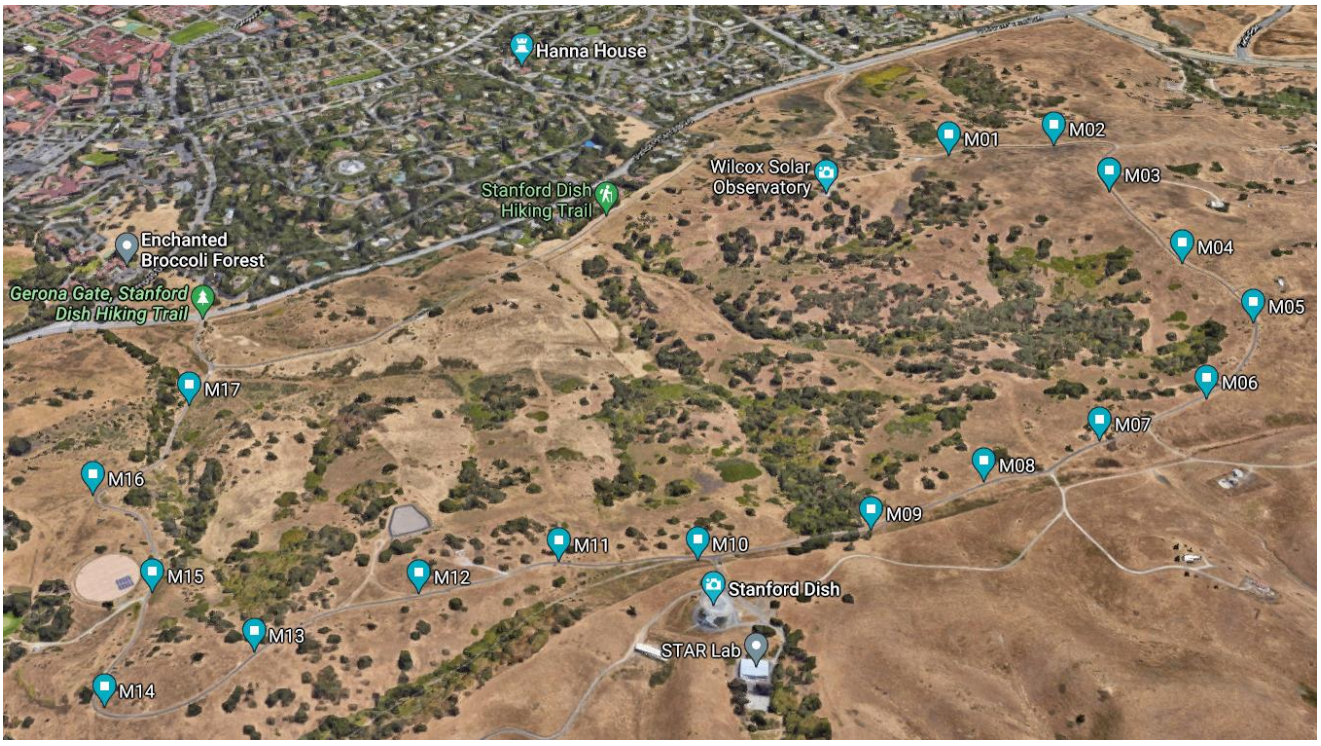
Seedlings planted in January 2020 grew well, yielding many flowers by summer, as seen in this photo taken on July 27, 2020 (photo by Hilary Bayer)

of 1,275 flowers. About 30% of these flowers had a sign of a visit by hummingbirds, which one can tell easily by looking at the stigma, the female reproductive part of the flower. Even though we did no further watering, these plants thrived and bloomed again in winter/spring of 2021.

Anna's hummingbird visiting the planted monkeyflower (photo by Tadashi Fukami)

7. Plan for 2021-2022

Encouraged by the success of the pilot work, helped greatly by Magic, we now plan to do the full-scale planting of *D. aurantiacus* at 16 sites (sites M02 to M17 shown on the map below), each with 32 plants, in November 2021 - January 2022. Building on Magic's extensive experience with completing similar planting projects on the Dish hill and throughout the Stanford campus over the past few decades, we will work on the full-scale monkeyflower planting with student volunteers in collaboration with the Haas Center. The plants will be watered until the beginning of the rainy season in fall 2022/winter 2023. We used the greenhouse on campus to grow more than 700 monkeyflower plants from seeds collected at JRBP. We will use these plants for the planting.



The 16 sites (sites M02 to M17) chosen for monkeyflower planting. We plan to plant 32 seedlings at each site. Site M01 is where the pilot planting was conducted.