University California, Santa Cruz

Younger Lagoon Reserve

Annual Report 2021-2022

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Executive Summary

Over the past year Younger Lagoon Reserve continued to thrive as a living laboratory and outdoor classroom focused on supporting University-level teaching, research and public service while meeting the campus' Coastal Long Range Development Plan (CLRDP) requirements for the protection and enhancement of all natural lands outside of the development areas of the Coastal Science Campus, including native habitat restoration of the 47-acre "Terrace Lands" as outlined in UCSC CLRDP and Coastal Development Permit. Over the past year we continued to increase our support of undergraduate course use. Most formal undergraduate education users were within the Environmental Studies and Ecology and Evolutionary Biology departments. Younger Lagoon Reserve-affiliated internships also supported over 60 undergraduate students who were involved with research, education, and stewardship. Prior to the COVID-19 pandemic, the majority of interns were involved in hands-on restoration and monitoring activities on the Terrace Lands engaging in a wide range of projects. When the COVID-19 pandemic began, the reserve internship program pivoted to virtual activities including readings, videos, and online discussion sections with reserve staff and local restoration experts. Although initially planned to be in place for only a short period of time (spring 2020), Younger Lagoon Reserve's virtual internship was offered for the entire FY 2020-2021 as the pandemic wore on. In the fall of 2021, we resumed our in-person internship program incorporating some virtual elements developed during the pandemic for a hybrid experience (e.g. weekly discussion sections continued to be held online). Despite the ongoing pandemic, Younger Lagoon Reserve continued to support use by other groups such as Cabrillo College, San Jose State University, Santa Clara University, the Santa Cruz Bird Club, local K-12 programs, and other community groups.

Restoration activities in FY 2021-2022 included weed control, planting of approximately 1.5 acres – including improved habitat for the California red-legged frog, and seed collection. Beyond restoration work we continued to conduct other on-the-ground stewardship activities including trash hauls, removal of illegal camps, fence repair, and public education. This was the 11th year of CLRDP compliance monitoring. Habitats monitored in 2022 included coastal scrub, coastal prairie, and wetland areas. YLR is meeting or exceeding restoration targets for all monitored sites and is meeting the restoration goals for Phase 2. FY 2021-2022 represented the 12th full year of implementation of the CLRDP Beach Access Management Plan related activities at Younger Lagoon Reserve. The University's NOID 12 (20-1) was approved by the California Coastal Commission (CCC) in October 2020 with the continuation of five special conditions related to increased public access to Younger Lagoon Reserve beach. With the approval of the CCC, some public access programming – including the free public beach tours, was temporarily suspended in March 2020 due to the COVID-19 pandemic. The free public beach tours resumed in April 2022. YLR is fulfilling all required public access requirements for the Younger Lagoon Reserve beach.

In Summary, despite the ongoing COVID-19 global health pandemic, YLR continued to offer excellent field locations for undergraduate, graduate, and faculty ecological research, support ongoing research and meet all CLRDP related activities and requirements.

Introduction

This report provides an overview of the activities that were conducted at Younger Lagoon Reserve (YLR) during the 2021-2022 fiscal year (July 1, 2021 - June 30, 2022). Despite the ongoing COVID-19 pandemic, Younger Lagoon continued to see increases in use and activity in general. During the COVID-19 pandemic, reserve staff found creative ways to maintain engagement with the reserve such as virtual class visits, tours, and internships. As the pandemic eased, reserve staff welcomed users back to the reserve for COVID-safe in-person and hybrid activities. Providing an outdoor classroom and living laboratory allows for experiential learning opportunities. These opportunities have profound impacts on students both professionally and personally. This was the eleventh year we had fulltime staff on site managing the Reserve. As a direct result, the level of academic and public engagement has increased and the Reserve is on target for implementing its obligations required under the Coastal Long Range Development Plan (CLRDP).

Younger Lagoon represents a unique reserve within the UCSC's Natural Reserves portfolio as it has open public access to a portion of the Reserve. Along with the challenges of public access (i.e. impacts to resources, protecting research equipment, protecting endangered and threatened species, implementing regulations, etc.) having public present on-site provides opportunities for outreach and education. The COVID-19 pandemic has highlighted the importance of high-quality open space for human health (i.e. green workouts, opportunities for mask-less conversations, a sense of connection with something larger than the present crisis, etc.) and public use of the reserve and CSC exploded during the pandemic. Due to the COVID-19 pandemic, and in response to UCSC's request for a COVID-19 emergency waiver, on July 10, 2020 the Coastal Commission issued a permit waiver to UCSC in support of COVID-19-related temporary closures and free beach tour suspensions (see UC Santa Cruz's Pub. Res. Code section 30611 notification letter to the Commission dated July 6, 2020). The entrance gate was closed to unauthorized vehicles for several months during FY 2020-2021, and as a result, the CSC took on something of an Open Streets atmosphere with members of the public rollerblading in the streets and families walking the trails. The entrance gate was fully reopened, and the free public beach tours reinstated in April 2022. During the past year, we continued to implement restoration activities on the Terrace Lands portion of the reserve and, as a direct result, interacted frequently with public users. These interactions have continued to provide opportunities for reserve staff and students to discuss the short and long-term objectives and goals of the restoration work, interpret the flora and fauna of YLR, and discuss ongoing planning and development efforts of the Coastal Science Campus (CSC).

CLRDP Activities

Overview

This year represented the 13th year of CLRDP related activities at Younger Lagoon Reserve. The California Coastal Commission certified the CLRDP for the "Terrace Point" property in 2008. In July of 2008, approximately 47 acres of natural areas of the "Terrace Point" property were incorporated into the University of California Natural Reserve System as part of UCSC's Younger Lagoon Reserve. The inclusion of the 47 acres into YLR, along with continued management of the lagoon portion of YLR, was a requirement of the California Coastal Commission for the UCSC Coastal Science Campus development.

The CLRDP requires that the entire Reserve be protected and used as a living laboratory and outdoor classroom and that the newly incorporated Natural Reserves lands are restored over a 20-year period. Fulfilling the University's mission to support research and teaching, we continue to incorporate research and teaching into all aspects of restoration, monitoring, research and protection throughout YLR. The increased lands and access to restoration and monitoring projects are providing expanded opportunities for undergraduate experiential learning opportunities via class exercises, research opportunities, and internships.

NOID 2 (10-1), NOID 9 (18-1), & NOID 12 (20-1) Beach Access Management Plan

This year represented the 11th full year of Beach Access Management Plan related activities at Younger Lagoon Reserve. In March 2010, the California Coastal Commission (CCC) approved the University of California's Notice of Impending Development for Implementation Measure 3.6.3 of the CLRDP (NOID 2). Implementation Measure 3.6.3 of the CLRDP required that (through controlled visits) the public have access to Younger Lagoon Reserve beach and that a monitoring program be created and implemented to document the condition of native flora and fauna within Younger Lagoon and its adjacent beach. The monitoring plan was to be implemented over a 5-year time period. At the end of the 5-year period (Winter 2015) results were to be compiled and included in a report that summarizes and assesses the effect of controlled beach access on flora and fauna. That report was submitted to the California Coastal Commission in 2016.

The CLRDP requires that University submit a NOID to the CCC that summarizes findings of the Beach Access Management Plan every five years. That NOID (NOID 9) was initially submitted in the Fall of 2016; however, it was withdrawn due to CCC staff workload and was resubmitted in summer of 2017. Although CCC staff recommended approval of NOID 9 as submitted, CCC Commissioners raised questions regarding beach access at the July 2017 meeting, and YLR staff withdrew NOID 9 prior to the Commissioners vote in order to try and better address these questions. The University resubmitted NOID 9 to the CCC in September 2018.
In September 2018, the Commission approved UCSC's NOID 9 to continue the beach tour program though through 2020 with the addition of five special conditions. These special conditions were at the suggestion of Commission staff, and included 1) requiring that the tours be offered without admission to the Seymour Center), 2) additional tour outreach and advertising, 3) additional tour signage, 4) additional tour monitoring and reporting requirements, and 5) a threat to open the beach to additional public access should the conditions not be met. Condition 5 has the potential to jeopardize not just the research integrity of the reserve, but also the security of the west side of the Marine Lab, including the seawater system and marine mammal research program.

The University submitted NOID 12 to the CCC in October 2020. In October 2020, the Commission approved UCSC's NOID 12 with the continuation of the five special conditions required in 2018.

Due to COVID-19 precautions and fiscal impacts of the pandemic, and in response to UCSC's request for a COVID-19 emergency waiver, on July 10, 2020 the Commission issued a permit waiver to UCSC in support of COVID-19-related temporary closures and free beach tour suspensions (see UC Santa Cruz's Pub. Res. Code section 30611 notification letter to the

Commission dated July 6, 2020). The Seymour Center was temporarily closed, and the free beach tour program was temporarily suspended in early March 2020 and the beach tour program remained suspended for the entire 2020-2021 fiscal year. The University restarted the free beach tour program in April 2022.

A detailed report on activities under the Beach Access Management Plan is included as Appendix 1. The NOID 12 Special Conditions Implementation Reports 2 & 3 are included as Appendix 5.

NOID 3 (10-2) Specific Resource Plan for the Enhancement and Protection of Terrace Lands at Younger Lagoon Reserve

The Resource Management Plan (RMP) within the CLRDP provides a broad outline with general recommendations and specific guidelines for resource protection, enhancement, and management of all areas outside of the mixed-use research and education zones on the CSC site (areas that will remain undeveloped). In addition to resource protection, the CLRDP requires extensive restoration, enhanced public access/education opportunities on site, and extensive monitoring and reporting requirements. The entire project is to be completed over 20 years and, as a condition of inception into the University of California Natural Reserve System, UCSC Campus has committed to providing perpetual funding for the project and continued management of YLR.

The SRP for Phase 1A of restoration (first 7 years) was approved by the CCC in September 2010 (NOID 3, 10-2). Phase 1A projects included Priority 1 weed removal, re-vegetation, baseline monitoring and selection of reference systems. FY 2017-2018 marked the conclusion of the SRP for Phase 1A.

The SRP for Phase 2 of restoration (second 7 years) was submitted to the CCC as part of the 2017-2018 Annual Report.

The SRP for Phase 2 of restoration outlined detailed success criteria for each of the reserve's habitat types (Ruderal, Coyote Brush Grassland-Scrub, and Grassland, Coastal Bluffs, Wetlands, and Wetland Buffers). These criteria set an initial threshold of species richness and cover for specific habitat types throughout the restoration area. These criteria were further refined at the recommendation of the SAC based on results from reference site monitoring of local coastal terrace prairie grassland, seasonal wetland, and coastal scrub sites (See 2009-2010, 2010-2011, 2011-2012, 2012-2013, 2013-2014, 2014-2015, 2015-2016, 2016-2017, 2017-2018, 2018-2019, 2019-2020, and 2020-2021 Annual Reports). Compliance monitoring for restored coastal scrub, coastal prairie, and wetland areas was conducted in FY 2021-2022. All sites monitored in 2021-2022 met or exceeded restoration targets and we are on track to meet all of the Phase 2 success criteria. A detailed compliance monitoring report is included in Appendix 2.

Restoration of the Terrace Lands continued throughout FY 2021-2022. Activities included weed control, planting, and seed collection.

<u>Future Restoration Monitoring Efforts (2022-2023)</u>

During the 2022-2023 field season, UCSC graduate students under the direction of professor Dr. Karen Holl will conduct restoration compliance monitoring at restoration sites 2, 4 and 6 years post planting and 5 years thereafter as per CLRDP requirements, as well as at any sites that have fallen below compliance standards.

NOID 5 (12-2) Public Coastal Access Overlook and Overlook Improvements Project

In August 2012, the California Coastal Commission (CCC) approved the University of California's Notice of Impending Development NOID 5 (12-2) Public Coastal Access Overlook and Overlook Improvements Project. Construction on the Public Coastal Access Overlook and Overlook Improvements Project ("Overlooks Project") began in the winter of 2012-2013 and was completed in the spring of 2013. The project consisted of three new public coastal access overlooks, and improvements to two existing overlooks at UCSC's Marine Science Campus. Several of the overlooks, which are sited at the margins of development zones, therefore are within what is now the Younger Lagoon Reserve: Overlooks C and A are within development zones at the margin of the YLR, while the sites of overlooks D, E and F are within areas incorporated into the YLR as a condition of approval of the CLRDP. The project constructed publicly-accessible overlooks from which to view the ocean coast (Overlook F), Younger

Lagoon (Overlook D), a seasonal wetland (W5) (Overlook A), and campus marine mammal pools (Overlook C) for which public access is otherwise limited due to safety hazards or for the protection of marine wildlife and habitats. The facilities include interpretive signs and public amenities such as bicycle parking and benches to enhance public access to, and enjoyment of these restricted and/or sensitive areas.

NOID 6 (13-1) Coastal Biology Building and Associated Greenhouses; Site Improvements Including Road, Infrastructure and Service Yards; Public Access Trails and Interpretative Panels; Wetland Connection in Specific Resource Plan Phase 1B; Sign Program; Parking Program; Lighting Plan.

In August 2013, the California Coastal Commission (CCC) approved the University of California's Notice of Impending Development NOID 6 (13-1) Coastal Biology Building and Associated Greenhouses; Site Improvements Including Road, Infrastructure and Service Yards; Public Access Trails and Interpretative Panels; Wetland Connection in Specific Resource Plan Phase 1B; Sign Program; Parking Program; Lighting Plan. This project included development of a new seawater lab building, three new parking lots along with a parking management program, a research greenhouse complex, and associated site work including storm water treatment and infiltration features. It also consisted of campus utility and circulation improvements to serve both the new lab building and future campus development under the CLRDP. The Project developed a complex of public access and interpretive facilities, including pedestrian access trails, interpretive program shelters, educational signage, and outdoor exhibits. This project initiated campus wide parking, sign, and lighting programs. This project also included mandated wetland restoration and habitat improvements as described in the Specific Resource Plan Phase 1B.

<u>SRP Phase 1B</u>

The Resource Management Plan within the CLRDP requires the reconnection of Upper Terrace wetlands W1 and W2. Wetland W1, on the western margin of the Upper Terrace, is a former agricultural ditch, probably constructed to drain the adjacent agricultural field. It is separated from wetland W2 (located immediately to the east) by a slightly elevated berm that may partially represent spoils left from the ditch construction. The SRP for Phase 1B of restoration detailed Younger Lagoon Reserve's approach for implementing these mandated wetland restoration and habitat improvements.

To reconnect hydrology between W1 and W2, five brush packs (ditch plugs) were installed within W1 in the summer of 2016 and 2017 (See 2016-2017 Annual Report and SRP Phase 1 Summary Report). SRP Phase 1B is now complete. As the hydrology of the site begins to shift to become more favorable to wetland plants, native wetland plants will be installed on the site. All of the brush packs are currently intact and functioning as designed. Although not yet observed, the ditch plugs may create small open water pool habitat and potentially provide new breeding habitat for amphibians.

<u>Domesticated Animals</u>

In 1999, when the University purchased the land for the expanded CSC, a special exception was made in the campus code to allow leashed dogs on the bluff top trail that rings the YLR Terrace Lands. Since that time, the site had become popular with dog owners, many of whom do not obey the leash law. The CLRDP requires that all domesticated animals be eliminated from the campus. Parallel to the start of construction, implementation of the campus "no dog" policy began in May 2015 in conjunction with activities under NOID 6 (13-1), and continued in FY 2021-2022. New trail signage was installed in 2018 to educate the community and the public about the policy change.

Scientific Advisory Committee (SAC) Meetings / Recommendations

A critical component of the CLRDP was the creation of a Specific Restoration Plan (SRP) guided by a Scientific Advisory Committee (SAC). The SAC is comprised of four members: Dr. Karen Holl (SAC chair) Professor and Chair of the Department of Environmental Studies at UCSC; Tim Hyland, Environmental Scientist, State Parks, Santa Cruz District; Bryan Largay, Conservation Director, Land Trust of Santa Cruz County; and Dr. Lisa Stratton, Director of Ecosystem Management, Cheadle Center for Biodiversity and Ecological Restoration, University of California, Santa Barbara (UCSB). SAC members met with reserve staff on-site and through email/phone consultation in FY 2021-2022. Discussion topics included current and future projects under the CLRDP, restoration, research, and teaching activities at YLR.

Monitoring Recommendations:

Coastal prairie is notoriously difficult to restore and maintain. The SAC recommends monitoring any sites that fall below target once a year rather than every other year and replanting or changing management regimes if sites does not rebound. Following the SACs recommendations, the 2012 coastal prairie restoration site – which was impacted by construction and drought and had fallen below its success targets in FY 2019-2020, was scrapped and completely replanted in FY 2020-2021. It will be monitored as a new site in 2022-2023.

Research Recommendations:

SAC members recommend that future research include investigations into methods for increasing the success of native annual forb plantings in coastal prairie restoration.

Summaries of ongoing research projects undertaken at the direction of the SAC are below. A full report on these projects is included in Appendix 3.

Large-scale Survey of California Grassland Restoration

From 2019-2021, UC Santa Cruz Department of Environmental Studies (ENVS) graduate student Justin Luong and ENVS faculty member Dr. Karen Holl conducted a large-scale survey of coastal CA grassland restoration projects across a 1000-km span from Santa Barbara to Humboldt. This study included 37 different restoration sites, one of which was Younger Lagoon Reserve. Overall, Luong and Holl found that coastal grassland restoration in California is successful at meeting project-based goals and a standard performance metric but common management practices may be resulting in biotic homogenization. Interviews with managers indicate almost all practitioners across this range select from a subset of the same seven species because they are known to grow or survive better to meet project goals. The research is currently being prepared to be submitted for publication in Ecological Applications.

Priority Effects in Annual Forb Establishment

In FY 2021-2022, Luong and Holl mentored undergraduate, Ernesto Chavez-Velasco in creating a priority effects field experiment in collaboration with YLR Restoration Field Manager Vaughan Williams. They investigated whether planting forbs 2 weeks earlier or native bunchgrasses 2 years earlier affects establishment and reproductive output of native forbs. They found strong that priority strongly favored forb species both in cover and seed production. UC Santa Cruz undergraduate student Jennifer Valadez will work with Luong to continue monitoring these plots in 2022 to assess germinant and survival counts of the targeted forb species that were used in the experiment. Jennifer Valadez will collect fruit/seed data from the plots in Summer 2022 and continue working with Holl and Luong into 2023 to continue collecting data on these plots and write a senior thesis. There are plans to write up this experiment after three years of data collection.

Effects of Scraping and Mounding on Annual Forb Establishment

In FY 2021-2022, Luong and Holl mentored undergraduate, Janine Tan in designing a soil scraping and mounding experiment in collaboration with Vaughan Williams and with the assistance of Jennifer Valadez. UC Santa Cruz undergraduate student Janine Tan will write this work as a senior thesis and Jennifer Valadez will continue to collect data on these plots in 2023. They were investigating whether shallow soil scraping and mounding affects establishment and reproductive output of native forbs. They assessed soil moisture, survival and plant community cover and Janine Tan will collect fruit/seed data in the summer of 2022. Initially, they found that that mounding increases soil moisture content and overall plant cover whereas scraping decreases soil moisture and total plant cover.

<u>Scientific Advisory Committee Management Recommendations:</u>

In FY 2021-2022 the SAC continued to provide input on the construction of a California Red-Legged Frog (CRLF) breeding pond in the upper terrace.

Upper Terrace CRLF Ponds

CLRDP RMP MM 9 states that the University shall "*Restore, consolidate, expand, and enhance wetlands on the northern part of the site (i.e., north of the Campus access road) to restore historic functional values lost during decades of agricultural use. The restoration program will* *include integrating the hydrology of Wetlands W1 and W2 to create a consolidated north-south area for wildlife movement to YLR. Hydrological surveys will be conducted by a qualified hydrologist to establish the elevations appropriate for optimizing expected wetland functioning. The area will be graded to provide a natural channel profile and gradient between the culvert at the Union Pacific Railroad tracks and the culvert outlet to Younger Lagoon on the west property line. The area west of the combined W1/W2 hydrologic corridor shall be restored as functioning wetland upland/transitional habitat, as shall buffer areas to the east. Maintain the CRLF potential habitat at the northern end of W-2.*

During the ACoE permitting process for projects impacting wetlands on the Coastal Science Campus (including restoration work in the upper terrace), the US Fish and Wildlife Service (USFWS) was brought in for Section 7 consultation. This discussion included members of the Natural Reserves and Physical Planning and Construction. In April 2014, USFWS approved the University's project as proposed and asked the campus to explore the feasibility of building CRLF pond(s) in the upper terrace as both a benefit to the local population and a demonstration of good faith / collaboration between UCSC and USFWS.

With the support of the reserve, campus agreed to explore the possibility and staffs from both the Resource Conservation District (RCD) and USFWS Coastal Program made a site visit to discuss feasibility and conduct initial studies in the summer and fall of 2014. RCD staff completed a soil evaluation in October 2014 and found groundwater at less than 5' deep at one of the sample points (in sandy soils and in very dry conditions) and believe that CRLF ponds could be engineered on site to hold water for long enough to support breeding. The RCD was ready to move forward with putting together a proposal for designing and building the ponds (this would have needed to be evaluated by the SAC with our existing RMP obligations in mind - e.g. reconnect wetlands 1 and 2, etc.); however, due to unresolved questions including permitting (e.g. would the RCD's permits work for the site within the permitting requirements and procedures for UC) and potential impacts to future projects, PP&C staff felt there was not enough information to move forward with further RCD planning and/or construction the ponds. Subsequently, PP&C staff engaged additional outside hydrologic and biologic consultants to do a feasibility study in 2016-2017. This study confirmed initial studies by the RCD, and indicated that CRLP Ponds could be engineered on site to hold water for long enough to support breeding. However, the study also warned that factors such as nearby bullfrog and crayfish populations could hinder the success of such ponds.

In 2019, USFWS Coastal Program contacted the University about an opportunity to have a CRLF breeding pond built on-site by the RCD at little to no expense to the University under the RCD's consolidated permitting program. Staff representing UCSC Physical Planning, Development, and Operations (PPDO, formerly PP&C), the UCSC NRS, the RCD, and USFWS Coastal Program in FY 2019-2020 to discuss the opportunity further and begin the planning process. The planning process – including design, continued throughout FY 2020-2021 and extended into FY 2021-2022. The SAC provided feedback on multiple rounds of draft designs that were incorporated into the final approved project.

In 2021, the RCD was able to obtain all the necessary project permits and approvals for construction of a CRLF breeding pond on the Coastal Science Campus. In the fall of 2021, the RCD partnered with the University to build a pond to improve breeding habitat for CRLF in the upper terrace. Reserve staff and student interns began replanting the project site with native species in the fall of 2021. The pond filled with water during the first large storm of the season and functioned as planned for the rest of the year. The pond retained water into the summer, which is the hydrological condition necessary for CRLF breeding and targeted by the design. Reserve staff and student interns conducted extensive biological monitoring of the pond throughout the year, including nighttime visual amphibian surveys, acoustic monitoring, invertebrate sampling. The pond was colonized by native Sierran treefrogs (*Pseudacris sierra*) and a small number of invasive American bullfrogs (*Lithobates catesbeianus*) in the early spring, but to date, no CRLF have been observed in the pond. CRLF egg masses require sturdy vegetation or other material upon which to attach. As the native plant species planted in 2021-2022 establish, we anticipate that the pond will support CRLF breeding.

The SAC is generally supportive of the idea of CRLF pond in the upper terrace as a way to 1) increase collaboration between UCSC, YLR, and the USFWS, 2) potentially provide opportunities for CRLF teaching, research and outreach on the reserve, and 3) meet habitat restoration and wetland reconnection goals. However, some SAC members have expressed concerns about 1) whether the ponds would function as expected and 2) more broadly, whether or not CRLF ponds are even necessary in our area. The SAC will continue to provide guidance on future pond management and monitoring efforts.

Photo Documentation

Photo point locations were established at ten locations within YLR. These locations were chosen to ensure coverage of all major areas on the Terrace. Photos were taken on May 10, 2022. At each photo point we collected the following information:

1. Photo point number
2. Date
3. Name of photographer
4. Bearing
5. Camera and lens size
6. Coordinates
7. Other comments

Photos are included in Appendix 4.

Restoration Activities

<u>SRP Phase 1 Implementation Summary</u>

The SRP for Phase 1A of restoration (first 7 years) was approved by the CCC in September 2010 (NOID 3, 10-2). The SRP for Phase 1B of restoration (upper terrace wetland work) was approved by the CCC in July 2013 (NOID 6, 13-1). Phase 1A projects included Priority 1 weed removal, re-vegetation, baseline monitoring and selection of reference systems. Phase 1B projects included work in wetland areas, including the reconnection of upper terrace wetlands 1 and 2. Both Phase 1A and Phase 1B of restoration are now complete.

Younger Lagoon Reserve successfully implemented Phase 1 of the Specific Resource Plan for the Enhancement and Protection of Terrace Lands at Younger Lagoon Reserve. Nearly all Priority 1 weeds have been eliminated from the Terrace Lands. Over ten acres were planted with native species during Phase 1. Nearly all of those plantings are meeting or exceeding their success criteria targets. Upper terrace wetland reconnection work has been completed. In addition, teaching, research, and public service was incorporated into every aspect of SRP Phase 1 implementation. (See 2009-2010, 2010-2011, 2011-2012, 2012-2013, 2013-2014, 2014-2015, 2015-2016, 2016-2017, 2017-2018, 2018-2019, 2019-2020, and 2020-2021 Annual Reports; and SRP Phase 1 Summary Report).

SRP Phase 2

The SRP for Phase 2 of restoration (second seven years) follows the same success criteria for each of the reserve's habitat types and encompasses approximately 8.5 acres of restoration. At the time the SRP for Phase 2 of restoration was written (2017-2018), we anticipated that Phase 2 restoration efforts would focus primarily on the middle terrace with some efforts occurring in other areas. The SRP for Phase 2 discusses the possibility of the upper terrace frog pond project occurring during Phase 2; however, it was not clear at the time the SRP for Phase 2 was written that the project would receive approval in time to occur during Phase 2. With the approval and successful construction of the pond, we will be focusing more of our efforts during Phase 2 on the upper terrace that initially anticipated. The total number of acres restored during Phase 2 and success criteria will remain the same. (See 2017-2018, 2018-2019, 2019-2020, and 2020-2021 Annual Reports; and SRP Phase 2).

FY 2021-2022 Restoration Activities

Restoration activities continued on the Terrace Lands of YLR and throughout the lagoon portion of the Reserve. Prior to the COVID-19 pandemic, implementation was conducted largely by undergraduate students and community volunteers; thus, utilizing the reserve in a manner consistent with the programmatic objectives (facilitating research, education, and public service) of the University of California Natural Reserves, as well as leveraging funding to increase restoration work. During the pandemic, implementation was conducted largely by undergraduate student employees and staff rather than undergraduate student interns and volunteers due to restrictions on in-person instruction and campus visitors. Undergraduate student interns and community volunteers returned to the reserve in the fall of 2021 as the pandemic eased. (Figure 1). Here we summarize some of the restoration activities that occurred on YLR during the past year.

Figure 1. Reserve staff and undergraduate student interns plant native seedlings at the upper terrace frog pond following the first winter storm.

<u>Priority One Weed Removal</u>

Under the SRP, all priority-one weeds (Ice plant, Jubata grass, Monterey cypress, Cape Ivy, Panic veldgrass, Harding grass, French Broom and Monterey Pine) are to be controlled as they are detected throughout the Terrace Lands. Elimination of reproductive individuals is the goal; however, YLR is surrounded by priority-one weed seed sources and it is likely that there will always be a low level of priority-one weeds persisting on the terrace. In FY 2021-2022, reserve staff conducted weed patrols of the entire terrace, continued removing ice plant from the coastal bluffs, removed all Jubata grass re-sprouts from the terrace, removed all French Broom re-sprouts from the terrace, and removed all Cape Ivy re-sprouts from the west arm of the lagoon. In FY 2022-2023, reserve staff will continue weed control projects and patrols. Due to the longlived seed bank of French Broom, proximity of mature Jubata grass and Panic veldgrass on adjacent properties, and known ability of Cape Ivy fragments to re-sprout, regular patrols and maintenance of these sites will be critical. Removal of new recruit Monterey Pine and Cypress will continue as will targeted removal of current individuals.

Seed Collection and Plant Propagation

In the summer and fall of 2021, reserve staff and student interns collected seeds for restoration growing. These seeds were propagated by the UCSC Teaching Greenhouse in the fall and winter of 2021/2022.

Restoration Planting

In FY 2021-2022, approximately 1 acre of wetland, coastal prairie, and scrub areas were planted with native seedlings (Figure 2).

Figure 2. 2022 Restoration Site.

Education

Instructional use at Younger Lagoon Reserve continued to be strong this year; however, due to the ongoing COVID-19 pandemic, some field trips were again canceled while others transitioned to remote or hybrid instruction. As the pandemic eased, students reported a deep sense of satisfaction in being together again outdoors. Courses encompassed a wide variety of disciplines. The steady course use is a direct result of having fulltime staff on site that are able to actively engage faculty and students through outreach efforts in the classroom as well as providing on-the-ground assistance in teaching activities – despite the pandemic. The proximity of Younger Lagoon to the campus enables faculty and students to easily use the Reserve for a wide variety of instructional endeavors ranging from Restoration Ecology to Natural History Illustration.

Undergraduate Students – Providing hands-on learning opportunities for future leaders

YLR's location on the UC Santa Cruz Coastal Science Campus and proximity to the UC Santa Cruz Main Campus make it an ideal setting for undergraduate teaching and research (Figure 3). In FY 2021-2022 the reserve hosted classes in Coastal Field Studies, Ecology, Ecology and Conservation in Practice Supercourse, Ecology and Society, Environmental Field Methods, Field and Lab Methods in Aquatic Science, Freshwater and Wetland Ecology, Herpetology, Introduction to Field Research and Conservation, Mammalogy, Molecular Ecology, Natural History Practicum, Natural History Illustration, Natural History of UC Santa Cruz, Ornithology, Plant Ecology, Restoration Ecology, Soil Science Practicum, and Systematic Botany of Flowering Plants (Table 1). Many field courses that were offered online or not offered at all during 2020-2021 resumed this year and class use rebounded to pre-pandemic levels.

Figure 3. Students from *BIOE 117 Systematic Botany of Flowering Plants* practice keying plants at Younger Lagoon Reserve. This course was taught in the Coastal Biology Building and students walked from their classroom to the field in minutes.

Internships

In FY2021-2022, YLR staff sponsored over 60 undergraduate interns through the UCSC Environmental Studies Internship Office. The students ranged from entering freshman to graduating seniors and spent between 6 and 15 hours a week learning about on-going restoration projects at the reserve. Interns participated in hands-on projects including invasive species removal, re-vegetation with native species, seed collection, and propagation; and virtual activities including readings, videos, and weekly online discussion sections with reserve staff and local experts. Student-interns report a deep appreciation for the opportunity to obtain experience in their field of study and build community – especially post-pandemic, with their fellow students (Figure 4).

Figure 4. Undergraduate student interns work together to silk screen t-shirts at the reserve.

Course Title	Institution (Department)	Instructor's Name
BIO 11C - Ecology	Cabrillo Community College	Alison Gong
ENVS 189 – Coastal Field Studies	San Jose State University	Rachel Lazzeri-Aerts
ENVS 151 – Restoration Ecology	Santa Clara University	Andy Kulikowski
BIOE 82 – Introduction to Field Research and Conservation	University of California, Santa Cruz (Dept. of Ecology and Evolutionary Biology)	Alison Gong
BIOE 107 – Ecology	University of California, Santa Cruz (Dept. of Ecology and Evolutionary Biology)	Marm Kilpatrick
BIOE 112 – Ornithology	University of California, Santa Cruz (Dept. of Ecology and Evolutionary Biology)	Bruce Lyon
BIOE 114/L – Herpetology	University of California, Santa Cruz (Dept. of Ecology and Evolutionary Biology)	Sean Reilly
BIOE 117/L – Systematic Botany of Flowering Plants	University of California, Santa Cruz (Dept. of Ecology and Evolutionary Biology)	Miranda Melen
BIOE 124/L – Mammalogy	University of California, Santa Cruz (Dept. of Ecology and Evolutionary Biology)	Gizelle Hurtado
BIOE 145 – Plant Ecology	University of California, Santa Cruz (Dept. of Ecology and Evolutionary Biology)	Ingrid Parker
BIOE 151ABCD/ENVS109ABCD – Ecology and Conservation in Practice Supercourse	University of California, Santa Cruz (Dept. of Ecology and Evolutionary Biology and Dept. of Environmental Studies)	Don Croll and Gage Dayton
BIOE 165 – Marine Conservation Biology	University of California, Santa Cruz (Dept. of Ecology and Evolutionary Biology)	Don Croll
CLEI 55 - College Eight: Service Learning Practicum	University of California, Santa Cruz (Rachel Carson College)	Susan Watrus

CLEI 55 - Sustainability Internship	University of California, Santa Cruz (Rachel Carson College)	Susan Watrus
ENVS 15 – Natural History of the UCSC Campus	University of California, Santa Cruz (Dept. of Environmental Studies)	Ryan Carl
ENVS 18 – Natural History Illustration	University of California, Santa Cruz (Dept. of Environmental Studies)	Emily Underwood
ENVS 83 / 183 - Younger Lagoon Reserve Stewardship Interns	University of California, Santa Cruz (Dept. of Environmental Studies)	Katie Monsen
ENVS 84 / 184 - Younger Lagoon Reserve Stewardship Interns	University of California, Santa Cruz (Dept. of Environmental Studies)	Katie Monsen
ENVS 100 – Ecology and Society	University of California, Santa Cruz (Dept. of Environmental Studies)	Greg Gilbert
ENVS 104A/L - Environmental Field Methods	University of California, Santa Cruz (Dept. of Environmental Studies)	Greg Gilbert
ENVS 160 - Restoration Ecology	University of California, Santa Cruz (Dept. of Environmental Studies)	Karen Holl
ENVS 167 - Freshwater / Wetland Ecology	University of California, Santa Cruz (Dept. of Environmental Studies)	Katie Monsen
KRES3 – Natural History Practicum	University of California, Santa Cruz (Kresge College)	Sean Reilly
OCEA/ESCI 150 - Field and Lab Methods in Aquatic Science	University of California, Santa Cruz (Dept. of Earth Sciences and Dept. of Ocean Sciences)	Carl Lamborg

Table 1. Younger Lagoon Courses

Research

Due in part to its relatively small size and lack of facilities, YLR is unlikely to host many single-site research projects in biology or ecology. However, as one of the few remaining coastal lagoons in California, YLR is well suited to act as one of many research sites in a multi-sited project. Additionally, the location on the Coastal Science Campus and close proximity to the residential campus makes it an ideal place for faculty to conduct pilot and our small-scale studies as well as for undergraduate research opportunities.

Last year, research conducted at Younger Lagoon Reserve resulted in the publication of five peer-reviewed articles. A list of those publication is below. The full articles are included as Appendix 6.

Holl, K.D., Luong, J.C. and Brancalion, P.H., 2022. Overcoming biotic homogenization in ecological restoration. Trends in Ecology & Evolution.

Luong, J.C., 2022. Nonperiodic grassland restoration management can promote native woody shrub encroachment. Restoration Ecology.

Luong, J.C. and Loik, M.E., 2022. Adjustments in physiological and morphological traits suggest drought-induced competitive release of some California plants. Ecology and Evolution, 12(4), p.e8773.

Luong, J.C. and Loik, M.E., 2021. Selecting coastal California prairie species for climate-smart grassland restoration. Grasslands, 33(1).

Wasserman, B., T. L. Rogers, S. B. Munch, and E. P. Palkovacs. 2022. Applying empirical dynamic modeling to distinguish abiotic and biotic drivers of population fluctuations in sympatric fishes. Limnology and Oceanography. 67: S403– S415. doi:10.1002/lno.12042

In FY 2021-2022 we approved thirteen research applications. Examples and summaries of new and ongoing research are included below.

Graduate Student Research Highlight: Impacts of Nitrogen Fertilizer on Microbial Mercury Methylation

Methylation of mercury (Hg) by microbes is a critical health concern and risk to biodiversity. The organometallic form of this neurotoxic element, methylmercury (MeHg), more readily bioaccumulates within marine food webs than does the inorganic form. Prior research on the impact of eutrophication on microbial Hg methylation has provided inconsistent answers as to whether addition of nutrients would have a positive or negative relationship with methylmercury production. UC Santa Cruz Ocean Sciences graduate student researcher Jeanette Calvin is investigating the impacts of nitrogen (nitrate and ammonium) and reduced sulfur on Hg biogeochemistry at Younger Lagoon - an estuarine wetland located in close proximity to agricultural sites (Figure 5). Her work will provide insight into dynamic lagoon processes that impact ecosystem and human health.

Faculty Research Highlight: Communication in Artemisia douglasiana

Primary investigator Dr. Rick Karbans (UC Davis) and his team are investigating the potential of shoots and individuals of Artemisia douglasiana to communicate using volatile and vascular cues. Their initial experiments are currently being conducted in the lab at UC Davis. Karbans and his team present potted *A. douglasiana* plants from the Bodega Marine Reserve with volatile cues from three sources: genetically identical tissues, tissues from genetically different individuals from Bodega Marine Reserve, and tissues from genetically different individuals from other populations, including Younger Lagoon Reserve. In future years, Karbans and his team may wish to conduct field experiments at the Younger Reserve.

Faculty Research Highlight: International Drought Experiment

Several UC Natural Reserve sites in California are participating in the International Drought Experiment. The experiment is compliant with the *DroughtNet* protocol for comparison to 100 other sites worldwide (drought-net.org). Effects of drought on plant growth and biodiversity are being measured at a number of grassland and shrubland sites along a north-south and coastal-inland gradient in California. At UCSC, professors Michael Loik, Kathleen Kay, and Karen Holl are collaborating with graduate student Justin Luong on this project.

In FY 2021-20122, International Drought Experiment activities at YLR included: 1) Measurement and monitoring of plots in accordance with the International Drought Experiment protocol; 2) Decomposition and soil sampling; 3) *Baccharis pilularis* measurements and community composition; 4) Glasshouse experiments on drought and competition; and 5) Publication of YLR IDE research. A full report on the International Drought Experiment is included in Appendix 3.

Figure 5. UC Santa Cruz Ocean Sciences graduate students Jeanette Calvin and Xinyun Cui conduct research at Younger Lagoon Reserve.

Public Service

Public service use at Younger Lagoon Reserve was lower again this year due to ongoing COVID-19 pandemic impacts to public programming; however, several public programs that were temporarily suspended during the pandemic – including the free beach tours, did resume in FY 2021-2022. Public service users encompassed a wide variety of groups. The continuation of public service use despite the ongoing pandemic is a direct result of having fulltime staff on site that are able to actively engage public groups through outreach efforts as well as providing on-the-ground assistance in public service activities. The proximity of Younger Lagoon to the town of Santa Cruz enables members of the public to easily use the Reserve for a wide variety of approved endeavors ranging from birding to K-12 teaching (Table 2, Table 3).

Seymour Marine Discovery Center Ocean Explorers Summer Camp

Every summer, the Seymour Marine Discovery Center offers a summer camp for youth ages 7-14. In FY 2021-2022, campers participated in multiple inquiry and observational activities in the lagoon area and Terrace Lands during each of the camp sessions.

Figure 6. Seymour Marine Discovery Center Ocean Explorers Summer Camp program participants explore COVID-safe birding with YLR Steward, Eric Medina at the Terrace Point overlook.

Reserve Use

Despite the ongoing COVID-19 pandemic, the greatest educational user group for YLR in FY 2021-2022 was once again undergraduate education. A breakdown of all user groups is included in Table 2. YLR was used by UC Berkeley, UC Davis, UC Irvine, UC Santa Cruz, San Jose State University CalPoly Humboldt, CalPoly San Luis Obispo, Cabrillo Community College, Santa Clara University, Audubon Society, Black Oystercatcher Monitoring Project, Kids in Nature, Santa Cruz Bird Club, Seymour Marine Discovery Center, UC Santa Cruz Retiree Association, California Department of Fish and Wildlife, Elkhorn Slough National Estuarine Research Reserve, Washington State University, and the Pacific Collegiate School (Table 3).

Table 2. Younger Lagoon Total Use

RESERVE USE DATA Fiscal year: 2021-2022

Campus: University of California, Santa Cruz
Reserve: Younger Lagoon Reserve

	UC Home		UC Other		CSU System		CA Comm College		Other CA College		Out of State College		International University		Government		NGO/Non-Profit		Business Entity		K-12 School		Other		Total	
	Users	UDs	Users	UDs	Users	UDs	Users	UDs	Users	UDs	Users	UDs	Users	UDs	Users	UDs	Users	UDs	Users	UDs	Users	UDs	Users	UDs	Users	UDs
UNIVERSITY- LEVEL RESEARCH																										
Faculty	5	67	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	67
Research Scientist/Post Doc	0	0	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	2
Research Assistant (non-student/faculty/postdoc)	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
Graduate Student	3	61	2	5	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	6	67
Undergraduate Student	8	67	2	2	1	30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	11	99
Professional	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	1	1
Other	0	0	1	2	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	2	3
SUBTOTAL	16	195	7	12	1	30	0	0	0	0	1	1	0	0	1	1	1	1	0	0	0	0	0	0	27	240
UNIVERSITY - LEVEL INSTRUCTION (CLASS)																										
Staff	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
Faculty	11	20	0	0	1	2	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	13	24
Graduate Student	28	32	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	29	33
Undergraduate Student	473	1684	0	0	45	45	20	20	6	6	15	30	0	0	0	0	0	0	0	0	0	0	0	0	559	1785
Professional	1	20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	20
Volunteer	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
SUBTOTAL	514	1757	0	0	47	48	22	23	6	6	15	30	0	0	0	0	0	0	0	0	0	0	0	0	604	1864
OTHER																										
Staff	11	37	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	11	37
Faculty	4	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	5
Undergraduate Student	16	16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	16	16
K-12 Instructor	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	16	0	0	1	1	0	0	5	19
K-12 Student	50	170	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	30	48	0	0	80	218
Professional	5	5	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	6	6
Other	26	26	0	0	0	0	0	0	0	0	0	0	0	0	0	0	17	33	0	0	0	0	266	1623	309	1682
Docent	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	15	15	15	15
Volunteer	15	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	26	0	0	0	0	15	15	32	56
SUBTOTAL	129	276	0	0	0	0	0	0	0	0	0	0	0	0	1	1	21	75	0	0	31	49	296	1653	478	2054
HOUSING																										
TOTALS	**659**	**2228**	**7**	**12**	**48**	**78**	**22**	**23**	**6**	**6**	**16**	**31**	**0**	**0**	**2**	**2**	**22**	**76**	**0**	**0**	**31**	**49**	**296**	**1653**	**1109**	**4158**

Table 3. Younger Lagoon Group Affiliations

University of California Campus	**Non-governmental Organizations**
University of California, Berkeley	Audubon Society
University of California, Davis	Black Oystercatcher Monitoring Project
University of California, Irvine	Kids in Nature
University of California, Santa Cruz	Santa Cruz Bird Club
	Seymour Marine Discovery Center
California State Universities	UC Santa Cruz Retiree Association
California State University, San Jose	
California State University, Humboldt	**Governmental Agencies**
California Polytechnic State University,	California Department of Fish and Wildlife
San Luis Obispo	Elkhorn Slough National Estuarine
	Research Reserve
California Community College	
Cabrillo Community College	
Other Colleges and Universities	
Santa Clara University	**K-12 Education**
Washington State University	Pacific Collegiate School

Summary

Despite the ongoing COVID-19 pandemic, FY 2021-2022 was another successful year for YLR. The reserve continued to move forward with restoration, initiated new projects, strengthened collaborations, and continued to develop online resources to meet user needs during the pandemic. The continuation of student and course use through the pandemic is a direct result of having superb staff on sight that are actively engaged with students, faculty, and the public. In turn, we are able to achieve our mission of supporting education, research, and public education as well as meet the environmental stewardship obligations the University of California has committed to with the California Coastal Commission and the State of California in general. We look forward to continuing this exciting and important work in FY 2022-2023.

UCSC Natural Reserves Advisory Committee

Charge
The committee provides oversight of on- and off-campus natural reserves of instructional and research interest. It is responsible for developing program vision and policy for the management and use of the UCSC Campus Reserve and of the four UC Natural Reserves System holdings: Año Nuevo Island Reserve, Landels-Hill Big Creek Reserve, Younger Lagoon Reserve and Fort Ord Reserve. The committee coordinates with the systemwide NRS Advisory Committee that advises on policy for all NRS reserves.

In addition to the chair (Faculty Director), membership of the committee is comprised of faculty advisors to each reserve, one faculty representative at large, one non-senate academic appointment, one staff representative, one graduate student and two undergraduate students. The Faculty Director, in consultation with the Dean and the Administrative Director of the UCSC Natural Reserves, appoints the committee. Membership terms begin September 1 unless otherwise specified.

DURATION OF APPOINTMENTS

Faculty Director: 5 years

Faculty Advisors: 3 years

Non-Senate Academic, Staff, and Students: 1 year

Members may be reappointed at the discretion of the Faculty Director in consultation with the Administrative Director.

Hours/Quarter: Chair/NRS Representative-20, Members-10
Reports to: Division of Physical & Biological Sciences Dean

MEMBERSHIPS

Faculty Director of the Natural Reserve System	Don Croll Professor, Ecology & Evolutionary Biology Long Marine Lab, Center for Ocean Health (831) 459-3610 – croll@biology.ucsc.edu
Younger Lagoon Reserve Faculty Advisor	Karen Holl Professor, Environmental Studies Environmental Studies Department (831) 459-3668 – kholl@ucsc.edu

Año Nuevo Reserve Faculty Advisor	Daniel Costa Professor, Ecology & Evolutionary Biology Long Marine Lab, Center for Ocean Health (831) 459-2786 – costa@biology.ucsc.edu
UCSC Campus Reserve Faculty Advisor	Greg Gilbert Professor, Environmental Studies Environmental Studies Department (831) 459-5002 – ggilbert@ucsc.edu
Fort Ord Reserve Faculty Advisor	Laurel Fox Professor, Ecology & Evolutionary Biology Coastal Biology Building (831) 459-2533 – fox@biology.ucsc.edu
Landels-Hill Big Creek Reserve Faculty Advisor	Peter Raimondi Professor, Ecology & Evolutionary Biology Long Marine Lab, Center for Ocean Health (831) 459-5674 – raimondi@biology.ucsc.edu
Faculty Advisor at Large	Erika Zavaleta Professor, Ecology & Evolutionary Biology Coastal Biology Building (831) 459-5011 – zavaleta@ucsc.edu
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8 Ex-Officio	Paul Koch Dean, Physical and Biological Sciences Division of Physical and Biological Sciences Dean's Office (831) 459-2871 – pbscidea@ucsc.edu
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	Patrick Robinson, PhD – Director Año Nuevo Reserve Long Marine Lab, Conservation Annex
	Elizabeth Howard, MA – Director Younger Lagoon Reserve Long Marine Lab, Conservation Annex (831) 459-2455 – eahoward@ucsc.edu
	Alex Jones, MS – Director

Campus Natural Reserve
Natural Sciences II, Rm 465

Joe Miller -- Director
Fort Ord Natural Reserve
UCMBEST
831-459-4971—jotmiller@ucsc.edu

Younger Lagoon Reserve Scientific Advisory Committee (SAC)

Charge

As outlined in the in the CLRDP, restoration, enhancement, and management activities on the Marine Science Campus will be guided by a Scientific Advisory Committee (SAC) that is made up of independent professionals and academicians experienced in and knowledgeable about the habitats of the natural areas on the Marine Science Campus. The SAC shall guide the development of Specific Resource Plans, which shall be consistent with the performance standards set forth in the Resource Management Plan (RMP), and which may be adapted periodically based on findings from ongoing restoration work. The RMP goals and performance standards may be adjusted as directed by the SAC in coordination with the Executive Director to ensure the success of Campus restoration, enhancement, and management efforts. As such, the RMP goals and performance standards are not static requirements per se so much as initial guidelines that may be refined during the SAC process so long as such refinement is consistent with current professional restoration, enhancement, and management goals and standards, and with achieving high quality open space and natural habitat area in perpetuity consistent with this CLRDP. RMP adjustments in this respect may require a CLRDP amendment, unless the Executive Director determines that an amendment is not necessary.

The committee provides guidance for the restoration, enhancement, and management efforts at YLR, and collaborates with YLR staff on the creation and implementation of the Specific Resource Plan as outlined in CLRDP Implementation Measure 3.2.10 (below).

Implementation Measure 3.2.10 – Natural Areas Habitat Management. *Within six (6) months of CLRDP certification, the University in consultation with the Executive Director of the California Coastal Commission shall convene a scientific advisory committee (SAC) to guide the restoration, enhancement, and management of natural areas (i.e., all areas outside defined development zones, except for Younger Lagoon Reserve) on the Marine Science Campus (see Appendix A). Natural areas restoration, enhancement, and management may be completed in up to three phases corresponding to dividing the natural area into thirds (i.e., where Phase 1 accounts for at least one-third of the natural area, Phase 1 plus Phase 2 accounts for at least two thirds, and all of the three phases together account for all of the natural area). All restoration, enhancement, and management activities shall be guided by Specific Resource Plans developed by the University in accordance with the SAC and the criteria contained in the Resource Management Plan (Appendix A) and current professional standards for such plans. The SAC shall be responsible for guiding development of Specific Resource Plans and shall complete its work on the Specific Resource Plan for Phase I restoration and enhancement efforts within four (4) months of convening. The content of Specific Resource Plans shall be consistent with the performance standards set forth in Appendix A, which may be adapted periodically based on findings from ongoing restoration work. The University shall file a Notice of Impending Development for Phase I work within one (1) year of CLRDP certification. All natural areas restoration and enhancement shall be completed within 20 years of CLRDP certification, with* *interim benchmarks that at least one-third of the restoration and enhancement shall be completed within seven years of CLRDP certification and that at least two-thirds shall be completed within 14 years of CLRDP certification.*

The SAC was seated in January 2009. In addition to the chair, membership of the committee is comprised of three independent professionals and academicians experienced in and knowledgeable about the habitats of the natural areas on the Marine Science Campus. Brief bios of the four SAC members are below.

Dr. Karen Holl- Professor, Environmental Studies, University of California at Santa Cruz (UCSC).

Dr. Karen Holl has been on the faculty in the Environmental Studies Department at the University of California, Santa Cruz for nearly 20 years. She has conducted research on restoration ecology in a wide variety of ecosystems, including tropical rain forests, eastern hardwood forests, chaparral, grassland, and riparian systems in California. She has published over 50 journal articles and book chapters on restoring damaged ecosystems and is on the editorial board of the journal Restoration Ecology. She teaches the Restoration Ecology class at UCSC and supervises many of the undergraduate students who work on the UCSC Natural Reserves. She regularly advises numerous public and private agencies along the Central California Coast on land management issues. She recently was selected as an Aldo Leopold Leadership Fellow. Dr. Holl's expertise in restoration ecology, experimental design and data analysis, as well as her affiliation with UCSC and her excellent rapport with University students and staff make her an irreplaceable member of the Scientific Advisory Committee.

Dr. Holl received a Ph.D. in Biology from Virginia Polytechnic Institute and State University, and a Bachelors degree in Biology from Stanford University.

Tim Hyland - Environmental Scientist, State Parks, Santa Cruz District.

Mr. Hyland has worked in the field of wildlands restoration for nearly 20 years. Much of his work has focused on coastal scrub, dune, and wetland restoration at sites throughout the Central Coast, including Wilder Ranch State Park (located approximately one mile west of YLR). He has extensive experience in restoration planning and implementation, vegetation mapping, exotic species control, and native plant propagation. In addition, Mr. Hyland is highly skilled in public education and outreach. His long tenure with California State Parks and direct experience in designing and implementing large-scale restoration projects make him a valuable member of the Scientific Advisory Committee.

Mr. Hyland has a B.A. from California Polytechnic State University, San Luis Obispo.

Bryan Largay – Conservation Director, Land Trust of Santa Cruz County.

Mr. Largay has worked in the fields of hydrology, water quality, and wetlands for fourteen years with a focus on restoration and wildlife habitat. He has conducted wetland restoration, watershed hydrology, and water quality investigations and designed measures to control erosion and treat water quality problems using vegetation. Much of his work has focused on collaborative water quality protection projects with agricultural landowners and growers. He has worked to solve water resource problems with a broad array of individuals, including scientists, planners, engineers, growers, private landowners, and contractors. Prior to joining the staff of The Land Trust of Santa Cruz County, he worked as the Tidal Wetland Project Director at Elkhorn Slough National Estuarine Research Reserve (ESSNER) and participated in the Tidal Wetland Project as a member of the Science Panel and Model Advisory Team. Mr. Largay's experience working on complex, large-scale restoration projects with agricultural neighbors in a non-profit setting make him a very important addition to the Scientific Advisory Committee.

Mr. Largay received an M.S. in Hydrologic Sciences at U.C. Davis, and a Bachelor's degree at Princeton University.

Dr. Lisa Stratton - Director of Ecosystem Management, Cheadle Center for Biodiversity and Ecological Restoration, University of California, Santa Barbara (UCSB).

Dr. Lisa Stratton has worked in the field of science-based restoration for nearly 20 years. She has extensive experience in restoration planning and implementation in conjunction with campus construction projects. Much of her work at UCSB has focused on involving students and faculty in the Cheadle Center's restoration projects. Dr. Stratton's work at the UCSB has provided her with a rare understanding of some of the unique challenges and opportunities YLR staff face as they undertake the restoration project at YLR. Her combined experience in wildlands restoration and management, scientific research, and working within the University of California system make her a very important member of the Scientific Advisory Committee.

Dr. Stratton received a Ph.D. in Botany and Ecology from the University of Hawai'i, a M.S. in Conservation Biology and Sustainable Development from the University of Wisconsin-Madison, and a Bachelors degree in Comparative Literature from Stanford University

Appendix 1. California Coastal Commission beach monitoring report

Younger Lagoon Reserve

Beach Monitoring Report

2022

Younger Lagoon Reserve staff conduct a COVID-safe fish seine.

Elizabeth Howard, MA
Younger Lagoon Reserve

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Appendices

Overview and Executive Summary

In March 2010, the California Coastal Commission (Coastal Commission) approved the University of California's Notice of Impending Development Implementation for Implementation Measure 3.6.3 of the CLRDP (NOID 10-1). NOID 10-1 requires that (through supervised visits) the public have access to Younger Lagoon Reserve beach and that a monitoring program be created and implemented to document the condition of native flora and fauna within Younger Lagoon and its beach. The monitoring plan was to be implemented over a 5-year time period. At the end of the 5-year period (Winter 2015) results were to be compiled and included in a report that summarizes and discusses the potential effect of controlled beach access on flora and fauna at Younger Lagoon and submitted as a NOID to the CCC.

The campus began implementing the public access plan and monitoring program in spring 2010, and submitted the report on the results of the monitoring to the Coastal Commission in February of 2016 as part of the Younger Lagoon Reserve Annual Report. The campus submitted NOID 9 (16-2) Public Access to and Within Younger Lagoon Reserve to the Coastal Commission in December 2016. At the request of local coastal staff, the campus withdrew NOID 9 (16-2) resubmitted it as NOID 9 (17-1) in June 2017. The campus presented NOID 9 (17-1) at the July 2017 CCC and although CCC staff found the NOID consistent with the CLRDP, a Commissioner requested the University provide significantly more tours to the beach and that children be allowed for free. The campus withdrew NOID 9 (17-1), made changes to address these requests, and resubmitted it as NOID 9 (18-1) in August 2018.

On September 13, 2018, the Coastal Commission approved UC Santa Cruz's NOID 9 (18-1) as consistent with UCSC's approved Coastal Long Range Development Plan with the addition of five staff-recommended special conditions. These included 1) Free Beach Tours, 2) Beach Tour Outreach Plan, 3) Beach Tour Signs, 4) Beach Tour Availability and Monitoring, and 5) Beach Access Management Plan Duration. Within 30 days of the approval (i.e., by October 13, 2018), UCSC was required to submit a plan for implementation of the special conditions to the Executive Director of the California Coastal Commission. The plan for implementation of the special conditions was submitted to the Executive Director of the California Coastal Commission on October 15, 2018. UCSC received feedback from Coastal Commission staff on the plan, and a revised plan for implementation of the special conditions was submitted to the Executive Director of the California Coastal Commission on December 15, 2018. The revised plan for implementation of the special conditions was approved by the Executive Director on January 30, 2019.

NOID 9 (18-1) Special Condition 4 required that at least every six months (i.e., by June 30th and December 31st each year), UCSC shall submit two copies of a Beach Tour Monitoring Report for Executive Director review and approval. UCSC's initial report on the implementation of these special conditions for the period of January 1, 2019 through June 30, 2019 was submitted on June 28, 2019. Upon review, local Coastal Commission staff requested more detail regarding the implementation of Special Condition 2. UCSC's revised report on the implementation of the special conditions for the period of January 1, 2019 through June 30, 2019 was submitted on September 5, 2019. The report for the period of July 1, 2019 through December 31, 2019 was submitted on December 23, 2019. The report for the period of January 1, 2020 through June 30, 2020 was submitted on June 30, 2020. The report for the period of July 1, 2020 through December 31, 2020 was submitted on December 22, 2020.

On October 8, 2020, the Coastal Commission approved UC Santa Cruz's NOID 12 (20-1) as consistent with UCSC's approved Coastal Long Range Development Plan with the continuation of five staff-recommended special conditions from NOID 9 (18-1), an increase in the number of participants per tour and an increase in outreach efforts. Within 30 days of the approval (i.e., by November 8, 2020), UCSC was required to submit a plan for implementation of the special conditions to the Executive Director of the California Coastal Commission. The plan for implementation of the special conditions was submitted to the Executive Director of the California Coastal Commission on November 6, 2020. The plan for implementation of the special conditions was approved by the Executive Director on November 12, 2020.

NOID 12 (20-1) Special Condition 4 requires that at least every six months (i.e., by June 30th and December 31st each year), UCSC shall submit two copies of a Beach Tour Monitoring Report for Executive Director review and approval. The report for the period of January 1, 2021 through June 30, 2021 was submitted on June 25, 2021. The report for the period of July 1, 2021 through December 31, 2021 was submitted on December 13, 2021. The report for the period of January 1, 2022 through June 30, 2022 was submitted on June 30, 2022.

This document serves as both a summary report for activities under NOIDs 2 (10-1), 9 (18-1), and 12 (20-1) that have taken place since our previous report at the end of fiscal year 2021 and a summary report for the entire 12-year monitoring program. All year's results are included. Data collected indicate that Younger Lagoon Reserve (YLR) supports a wide variety of native flora and fauna, provides habitat for sensitive and threatened species, supports a very unique beach dune community, and is extensively used for research and education. In general, in comparison to the other local beaches surveyed native plant species richness is greatest at YLR and Natural Bridges; however, there is quite a bit of annual variation among the sites. A parameter that we quantified in 2012, and is evident from visual observation and photo documentation, is the presence of dune hummocks and downed woody material at YLR, both of which are almost entirely absent at local beaches due to human use. These features provide habitat for plant species such as the succulent plant dudleya, which grow on downed woody material and dune hummocks at YLR, as well as burrowing owls that use burrows in hummocks and seek shelter beneath downed woody material at YLR.

The relatively natural state of YLR beach and dune vegetation is unique among most pocket beaches in Santa Cruz County and likely represents a glimpse into what many of the pocket beaches in the greater Monterey Bay area looked like prior to significant human disturbance. Open access to the beach would likely result in the loss of the unique ecological characteristics of the site, likely have a negative impact on sensitive and protected species and certainly reduce its effectiveness as a research area for scientific study. Controlled beach access through the Seymour Center docent led tours, provides an appropriate level of supervised access that enables people to see and learn about the lagoon habitat while limiting impacts to the system. It is important to note, however that avian data collected during the 2020 and 2022 docent led beach tours indicate that the tours have a significant negative impact on birds (see NOID 9 (18-1) Special Conditions Implementation Report 4, December 23, 2020 and NOID 12 (20-1) Special Conditions Implementation Report 1, June 25, 2021, Special Conditions Implementation Report 2, December 13, 2021, and Special Conditions Implementation Report 3, June 30, 2022). We recommend that the current docent-guided tour program continue while we continue to monitor the biological impacts of the tours.

Although only required to monitor the YLR beach, YLR staff, faculty, and the Scientific Advisory Committee decided to monitor nearby beaches with varying levels of use (Natural Bridges and Sand Plant Beach) during the first 5-year period in order to examine differences in the flora, fauna and use among the three sites. This effort required hundreds of hours of staff and student time, as well as coordination with State Parks staff. As reported in the 2015 YLR Beach Monitoring Report, beginning in the summer of 2015 and moving forward, YLR staff will continue to monitor YLR as required in IM 3.6.3; however, we will no longer monitor at Natural Bridges State Beach or Sand Plant Beach as the previous 5 years of data collection have provided us with adequate information to assess beach resources.

Introduction

Over 50 years ago, the University of California Natural Reserve System (UCNRS) began to assemble, for scientific study, a system of protected sites that would broadly represent California's rich ecological diversity. Today the UC Natural Reserve System is composed of 41 reserves that encompass approximately 750,000 acres of protected natural land available for university-level instruction, research, and public service. The University of California Natural Reserve System supports research and education through its mission of contributing "*to the understanding and wise management of the Earth and its natural systems by supporting university-level teaching, research, and public service at protected natural areas throughout California*." By creating this system of outdoor classrooms and laboratories and making it available specifically for long-term study and education, the NRS supports a variety of disciplines that require fieldwork in wildland ecosystems. UC Santa Cruz administers four UC Reserves: Younger Lagoon Natural Reserve, Año Nuevo Island Reserve, Landels-Hill Big Creek Reserve, and Fort Ord Natural Reserve.

The objective of the beach monitoring program is to document the presence and distribution of flora and fauna within Younger Lagoon Natural Reserve (YLR) and to evaluate changes in distribution and density over time. Additionally, YLR staff decided to monitor nearby beaches with varying levels of use (Natural Bridges and Sand Plant Beach) in order to examine differences in the flora and fauna among the three sites. Importantly, the data collected in this study provides a quantitative assessment of various attributes (species composition, abundance, etc.) but it is realized that the sites vary significantly from one another and that there is no replication. Thus, although these data comparisons are informative there are significant constraints that make meaningful statistical comparisons between the sites impossible. As such, results shouldn't necessarily be used to create strict prescriptions.

This report is a report for activities under NOIDs 2 (10-1), 9 (18-1), and 12 (20-1) during Fiscal Year (FY) 2021-2022 (July 1, 2021 – June 30, 2020) which surveyed YLR. In addition, although we are no longer monitoring Natural Bridges and Sand Plant beaches, we have included all year's results from all sites in this report in order to show the entire effort to date. Data for each monitoring objective have been added to previous year's data; thus, the results for this reporting period have been combined with all previous findings. As a result, this report provides a running summary of our findings starting from the inception of the study and running through the end of FY 2021-2022.

Younger Lagoon Access History

History of Public Access to Younger Lagoon Beach

Prior to 1972, Younger Beach was privately owned and closed to the public. The owners (Donald and Marion Younger) actively patrolled for, and removed, trespassers from their property, including the beach. In 1972, the Younger Family donated approximately 40 acres of their property to the University of California for the study and protection of the marine environment. These lands included Younger Lagoon and Beach (approximately 25 acres), and an adjoining parcel of land (approximately 15 acres) which became the site of the original Long Marine Laboratory (LML). At the time of their donation, Donald and Marion Younger intended that the lagoon, beach and surrounding slopes be protected in perpetuity by the University as a bird sanctuary.

In the years between the donation of the property and the start of LML construction (1976), the University leased the future LML site back to farmers who had been farming the property for the Younger family prior to the donation. During those years, the same no trespassing rules for the beach were enforced as they had been when the property was owned by the Younger family.

Once construction of LML began in 1976, the land was no longer under the watch of the farmers, and public pressure on the beach began to increase. Many Santa Cruz locals remember the next several years at Younger Beach fondly as it became a popular nude beach. The increased public access had a noticeable impact on the flora and fauna of the beach, and was not in accordance with the intention of the original donation by the Younger family. By 1978 discussions had begun between the University and the California Coastal Commission regarding the impact of uncontrolled public access to the beach. In 1981, it was decided that the impacts to Younger Beach were significant and the California Coastal Commission, under coastal permit P-1859, closed uncontrolled access to the beach.

After the approval of coastal permit P-1859, the University began to actively patrol the beach for trespass, educate the public about the closure, and use the site for research and education. After YLR was incorporated into the UCNRS in 1986, users were required to fill out applications, or contact NRS staff, for specific research, education, or outreach efforts. As the LML campus grew, a protective berm and fencing were constructed around the perimeter of the lagoon, and informational 'beach closed' signs were posted on the cliffs above the beach. Over time, trespass decreased and the reduced public access had a noticeable positive impact on the flora and fauna of the beach.

Public access to YLR beach came to the forefront again during the CLRDP negotiation process (2000-2008). At the time negotiations began, YLR supported a rich composition of plant and animal species despite being surrounded by agricultural and urban development. Reserve staff were concerned that any increase in public access could threaten the already heavily impacted habitat. At the time of CLRDP certification (2010), all parties agreed to the Beach Access Management Plan outlined in NOID 10-1. Under the Beach Access Management Plan, the YLR beach remains closed to unsupervised public access and the reserve is implementing a management and monitoring plan that includes docent-guided tours.

Because of the importance of maintaining a natural and pristine environment (Figure 1) and protecting scientific studies and equipment, uncontrolled access to YLR is not allowed. Uncontrolled use of YLR is likely to have a negative impact on native coastal flora and fauna that inhabit the reserve, hamper research endeavors, and impact the area for future scientific and educational endeavors. Rather than an open public access policy, users are required to fill out applications, or contact NRS staff, for specific research, education, or outreach efforts. In 2010 YLR began hosting docent-guided tours that are offered by the Seymour Marine Discovery Center (Seymour Center).

Beach Access Tours

Due to COVID-19 precautions, the Seymour Center was temporarily closed and the free beach tour program temporarily suspended in March 2020. The University restarted the free beach tour program in April 2022 (see UC Santa Cruz's Pub. Res. Code section 30611 notification letter to the Commission).

From 2010 - 2017, docent-led beach tours were offered twice monthly through the Seymour Marine Discovery Center (Seymour Center). Starting in January 2018, tours are offered twice a month during the slower fall and winter months (October-February), and four times a month during the busier spring and summer months (March-September), for a total of 38 tours per year. From 2010-2018, these tours were offered free with admission to the Seymour Center. Starting in 2019, these tours are now offered for free. In addition, all of the docent led daily tours run by the Seymour Center (prior to the COVID-19 pandemic, approximately 1,500 tours annually) include an informational stop about YLR that includes visual access to the beach.

The extent of the beach access area varies depending on tidal conditions and the location of plants, as foot traffic is only permitted seaward of the dune vegetation. Thus, the exact access area may vary slightly from the areas depicted in Figure 2 below and Figure 3.11 of the CLRDP. The trail provides an interpretive experience for visitors that begins with a narrative history of the UC Natural Reserve System (UCNRS), an overview of the lagoon, a walk through a restored coastal scrub habitat with opportunities to view the rear dune, and ends on the beach. Tours are led by Seymour Center docents trained in the natural history and ecology of YLR and provide detailed information about flora, fauna, geology, and the UCNRS. Tour curriculum, which was first presented to the Seymour Center docents during the regular winter docent-training program in 2010, focuses on the unique ecology of the YLR beach.

In addition to the docent-guided beach tours, visual access to the lagoon and back dune is provided to the public via Overlook E along McAllister Way. Overlook E is open to the public from dawn to dusk. Visual access to the Younger Lagoon beach and information about Younger Lagoon Reserve is also provided to all visitors taking the Seymour Center's docent-guided Reserved and Daily Tours via the Overlook C. Prior to the COVID-19 pandemic, nearly 25,000 visitors annually took these tours.

In order to maintain public access and engagement during the COVID-19 pandemic, the University created a virtual bilingual beach tour that is available on the Seymour Center and Younger Lagoon Reserve websites. The virtual tour allows visitors from around the world to learn about the unique ecology and programs at the reserve in English and Spanish from the comfort of home.

The virtual tour websites feature a map of the reserve with marked locations where visitors can click to watch videos about the features of each type of habitat.

Virtual Tour Links:
English: https://arcg.is/11m1Ga
Spanish: https://arcg.is/0q0Czv

A UC Santa Cruz undergraduate student created the virtual tour websites and edited the videos as part of an internship project. This student completed all of the work on this project remotely, including learning about the reserve itself. A Younger Lagoon Reserve undergraduate student employee who assisted with the free in-person tours prior to the pandemic acts as the on-camera guide for both tours.

Public Education and Outreach Programming on the Coastal Science Campus

Seymour Marine Discovery Center

The free docent guided beach tours are part of broader public education and outreach programming on the Coastal Science Campus offered through the Seymour Center. Prior to the COVID-19 pandemic, nearly 70,000 people visit the Seymour Center, and nearly 15,000 visitors take docent-guided tours annually. The Seymour Center provides marine science education to hundreds of classes, comprised of thousands of students, teachers, and adult chaperones from across the country. Many of the classes served come from schools classified as Title 1—schools with high numbers of students from low-income families. Scholarships are made available to Title 1 schools, making it possible for students to participate who would not otherwise have the opportunity to experience a marine research center. Teachers often incorporate the Seymour Center into their weeklong marine science field study courses.

Every year, dozens of children ages 7-14, enrolled in weeklong summer science sessions known as Ocean Explorers. Students actively learn about and participate in marine research at the Seymour Center and Long Marine Laboratory, where participants work alongside marine mammal researchers and trainers. Participants gain experience with the scientific process, focusing on honing their observation and questioning skills. Ocean Explorers also investigate the coastal environment at field sites around Monterey Bay, including rivers and watersheds, sandy beaches, rocky intertidal areas, and kelp forests by kayak. Young participants generally come from Santa Cruz, Santa Clara, and San Mateo Counties. Full and partial scholarships are extended to low-income participants. After being cancelled in summer 2020 due to the COVID-19 pandemic, Ocean Explorers was offered in the summer of 2021.

While part of UC Santa Cruz, the Seymour Center must raise its ~$1.5 million budget annually (including all operating costs, salaries, and benefits) from earned revenue, private donors and grants. Earned revenue—admissions, program fees, facility rentals, and the Ocean Discovery Shop—makes up approximately half of its general operating requirements.

The Seymour Center actively promotes its activities with press releases and calendar listings throughout the region. Every year, traditional print ads are placed in newspaper and magazines. The Seymour Center's activities are also often covered in the local newspaper, the Santa Cruz Sentinel. Public radio ads run throughout the year on the NPR-affiliate, KAZU.

Coupons for discounted admissions are available in various formats. The most highly used program is through the many Bay Area municipal libraries. Called Discover and Go, hundreds of families from across the region utilize these discount coupons. The Seymour Center continued to connect with the public through Facebook, Twitter, Instagram, Pinterest, Flickr, and bi-monthly e-blasts.

Watsonville Area Teens Conserving Habitat (WATCH)

Prior to the COVID-19 pandemic, the Seymour Center, Younger Lagoon Reserve and the Monterey Bay Aquarium partnered to support high school students in the Watsonville Area Teens Conserving Habitats (WATCH) program. WATCH students from Aptos High School design and carry out field-based research projects in Younger Lagoon Reserve on topics including endangered fish, aquatic invertebrates, and birds. These students make repeated visits to the Reserve throughout the year. This program is currently paused due to the pandemic. Find out more at: https://www.montereybayaquarium.org/education/teen-programs/watsonville-area-teens-conserving-habitats-watch.

Community Bioblitz
Due to the COVID-19 pandemic, the annual Younger Lagoon Reserve Bioblitz / California Academy of Sciences was again canceled this year. A bioblitz is a community event that brings together a wide variety of people – citizen scientists - to rapidly inventory the living organisms found in a particular place. The Younger Lagoon Reserve Bioblitz is held during the spring, and is open to members of the public. Participants explored the lagoon and beach areas as part of this event. A link to the page advertising this community event can be found here: https://www.inaturalist.org/projects/younger-lagoon-reserve-bioblitz-2020

Volunteer Stewardship Days
This year, Younger Lagoon Reserve hosted several CPVID-safe volunteer stewardship days. These events are advertised on social media and open to the public. Volunteer stewardship days provide members of the public with the opportunity to learn about the reserve and its unique habitats, wildlife, research, restoration, and teaching programs while giving back.

Figure 1. Burrowing owl on the beach at Younger Lagoon.

Study Areas

Flora, fauna, and human use were monitored at Natural Bridges State Park, Younger Lagoon Reserve, and Little Wilder/Sand Plant Beach from 2010-2015 (Figure 2). These three sites have similar characteristics (all have beach and lagoon habitat), are within close proximity to one another, and experience varying levels of human use. Although site characteristics are similar in many ways, they are also different in many ways, and these differences likely influence species composition. Three of the primary differences among the sites are human use levels, composition of adjacent upland habitat, and the overall size of the beach and wetland areas. Starting in FY 2015-2016 and moving forward, only Younger Lagoon Reserve has been and will continue to be monitored.

Younger Lagoon Reserve

Younger Lagoon Reserve is located in Santa Cruz County, approximately 4.5 miles from the main UC Santa Cruz campus; adjacent to the UC Santa Cruz Long Marine Laboratory. One of the few relatively undisturbed wetlands remaining on the California Central Coast, Younger Lagoon Reserve encompasses a remnant Y-shaped lagoon on the open coast just north of Monterey Bay. For most of the year, the lagoon is cut off from the ocean by a sand barrier. During the winter and spring months, the sand barrier at the mouth of Younger Lagoon breaches briefly connecting the lagoon to the ocean. The lagoon system provides protected habitat for 100 resident and migratory bird species. Approximately 25 species of water and land birds breed at the reserve, while more than 60 migratory bird species overwinter or stop to rest and feed. Opossums, weasels, brush rabbits, ground squirrels, deer mice, coyote, bobcat, woodrat, raccoon, and skunk are known to occupy the lagoon; gray and red foxes as well as mountain lion have also been sighted. Several species or reptiles and amphibians, including the California Red-legged Frog, also are found in the Reserve. Reserve habitats include salt and freshwater marsh, backdune pickleweed areas, steep bluffs with dense coastal scrub, pocket sand beach, grassland, and dense willow thickets.

Sand Plant Beach ("Little Wilder")

Sand Plant Beach is located in Santa Cruz County, approximately 1.5 miles west of YLR adjacent to Wilder Ranch State Park. Sand Plant Beach is approximately 23 acres and includes a pocket beach, dunes, cliffs and lagoon. It is open to the public for recreational use from dawn until dusk, 365 days a year; however, requires a hike to get to it and thus experiences less human use than many of the more accessible beaches in Santa Cruz. The surrounding Wilder Ranch State Park covers approximately 7,000 acres and allows human, bike and equestrian access. Much of the interior lagoon/upland habitat has been modified for agricultural production and/or ranching over the past century. Today most of the vegetation that persists inland of the lagoon is dominated by freshwater emergent vegetation and willow thickets. Major wetland restoration projects have increased native flora and fauna in the area (Friends of Santa Cruz State Parks, 2010).

Natural Bridges Lagoon

Natural Bridges Lagoon is located in Santa Cruz County, approximately 0.5 miles east of YLR on the urban edge of the city of Santa Cruz CA in Natural Bridges State Park. Natural Bridges Lagoon, beach, and State Park encompasses approximately 63 acres and includes a wide pocket beach, lagoon, cliffs, and diverse upland habitat (scrub, grass, iceplant, willow thicket, live oak, eucalyptus, and cypress). The park is world-renowned for its yearly migration of monarch butterflies and famous natural bridge. Natural Bridges State Park allows human access as well as dogs that are on leash and remain on paved roads and in parking lots (Friends of Santa Cruz State Parks, 2010). The beach is a popular destination at all times of the year; however, it is especially popular in the spring, summer, and fall months.

Figure 2. Study Areas.

Methods

User Data

User data from tours conducted by the Seymour Center, as well as research and education use of YLR, were recorded and maintained by Seymour Center and YLR Staff. User data from educational programs and fee collection are recorded and maintained by California State Parks staff for Natural Bridges State Parks. No user data was available for Sand Plant Beach.

Human Beach Use

We used remote cameras to quantify human use quarterly througout the study peroiod. Cameras were placed along the eastern edge of Sand Plant Beach and Natural Bridges Beach from FY 2010-2011 – FY 2014-2015 and at the western edge of Younger Lagoon from FY 2010-2011 – present with each separate quarterly sampling events each consisting of two days. Cameras were set to automatically take photos at 15 minute intervals. Number of people were quantified for 15 minute intervals during the day (camera times varied across sampling periods due to day length and postion; however, were standardized within each sampling period). The total survey area varied between sites and among individual sampling efforts due the placement of the camera and available habitat for human users at the time of the survey (i.e. often less beach area surveyed at Sand Plant Beach compared to Younger Lagoon and Natural Bridges). In order to control for area, specific regions of photos were chosen and number of individuals within each region were counted; thus, the number of people counted per unit area and time was standardized. We used the largest survey area during each sampling period to standardize use within each specific region of the beach during each sampling effort. Thus, if a particular site had more or less habitat monitored, the number of individuals was standardized across sites making comparisons comparable.

Photo Documentation of Younger Lagoon Natural Reserve

Photo point locations were established at four locations within YLR (Figure 3). These locations were chosen to ensure coverage of all major areas of the beach. Photos were taken once during the reporting period. At each photo point we collected photo point number, date, name of photographer, bearing, and camera and lens size.

Tidewater Goby Surveys

Tidewater goby surveys were conducted quarterly throughout the study period. Surveys were conducted using a 4.5 ft x 9 ft beach seine with 1/8 inch mesh. The objectives of the surveys were to document tidewater goby presence and evidence of breeding activity (determined by the presence of multiple size/age classes). All fish were identified to species and counted. When individuals exceeded ~50 per seine haul, counts were estimated. Sampling was conducted with the goal of surveying the various habitats within each site (e.g. sand, sedge, willow, pickleweed, deep, shallow, etc.); thus, different numbers of seine hauls were conducted at each site. Species richness was compared among sites.

Figure 3. Locations of monitoring points, plots, and regions for YLR beach. Monitoring areas varied between sampling efforts depending upon the high water mark, vegetation patterns, and water levels.

Species Composition and Coverage of Beach Dune Vegetation

Dune vegetation from the lowest (nearest to the mean high tide line) occurring terrestrial plant to 10 meters inland into the strand vegetation was surveyed quarterly throughout the study period. The exact location and extent of the area surveyed each time varied depending upon the location of the "lowest" plant detected during each sampling effort. At each location we established a 50-m east-west transect across the dune vegetation and measured the distance from the estimated mean high tide line to the "lowest" plant on the beach. Herbaceous species composition was measured by visual estimation of absolute cover for each species in ten 0.25 m^2 quadrats along the transect. Quadrats were placed every 5 m on alternating sides of the transect starting at a randomly selected point between 1 and 5 meters (a total of 10 quadrats per transect). A clear plastic card with squares representing 1, 5, and 10% of the sampling frame was used to help guide visual cover estimations. Species cover (native and exotic), bare ground, and litter were estimated at 5% intervals. Litter was specifically defined as residue from previous year's growth while any senescent material that was recognizable as growth from earlier in the current growing season was counted as cover for that species. After all cover estimates had been made, we conducted surveys within 2 m of either side of the transect (a 4 × 50 m belt). In the belt transects, individual plants were recorded as either seedlings or greater than 1 year old. Presence of flowers and seeds was also noted.

Non-avian Vertebrate Monitoring

Tracks

Vertebrate tracks were measured using raked sand plots at each site quarterly throughout the study period. Tracking stations were placed throughout the beach area in constriction zones where vegetation was absent. The objective of these surveys was simply to detect what species use the beach habitat. As such, size of plot varied from approximately depending upon the amount of available open sandy area at each location. Track stations were raked each evening and checked for tracks in the morning. Stations remained open for two days during each monitoring bout. Tracks were identified to species when possible. Species composition was summarized; however, abundance was not quantified due to the fact that most often tracks cannot be used to identify individual animals (e.g. a single individual could walk across the plot multiple times).

Small Mammals

Sherman live traps were placed for two nights every quarter of the study period - a total of 30 traps were placed used (60 trap nights per sampling bout). Traps were set at dusk and collected at dawn. Each trap was baited with rolled oats and piece of synthetic bedding material was placed in each trap to ensure animals did not get too cold. Individuals were identified to species, marked with a unique ear tag, and released at the site of capture.

Invertebrate Monitoring

Terrestrial invertebrates on beach habitat were monitored by placing 12 oz plastic containers (pit fall traps) at each tracking station (one at each corner of the plot) during tracking efforts. Traps were buried to the lip of the container and checked each morning and all individuals were collected, identified, and counted.

Avian Monitoring

We conducted ocular surveys of birds on the beach, lagoon, and cliff habitats quarterly throughout the study period. Survey locations were selected along one edge of the beach on the cliff. At Sand Plant Beach the entire beach area, fore portion of the lagoon, and western cliff were surveyed from the eastern edge of the lagoon (FY 2010-2011 – FY 2014-2015). At YLR the entire beach area, fore portion of the lagoon, and western cliff were surveyed from the eastern edge of the lagoon and the top and western face of the rock stack that is located at the beach/ocean edge was surveyed (FY 2010-2011 – present). At Natural Bridges surveys were conducted from the eastern edge of the beach on the cliff adjacent to De Anza Mobile Home Park or from the beach to the west; fore lagoon and approximately the western ¼ of the beach area (including beach/ocean interface) was included in the survey area (FY 2010-2011 – FY 2014-2015). Survey areas were chosen with the goal of surveying approximately the same area and types of habitat. Counts were recorded quarterly throughout the study. Surveys were conducted in the dawn or dusk hours within approximately 2 hours of sunrise or sunset and of one another. Data from the two days during each sampling effort were combined and individuals were identified and counted.

Results

User Data

Younger Lagoon Reserve

Despite the ongoing COVID-19 pandemic, a wide variety of public and non-profit research and educational groups used Younger Lagoon in FY21-22 (Table 1). The greatest educational user group for YLR was undergraduate education, a breakdown of all user groups is included in Table 2. The greatest user group was "other" which consists primarily of members of the public visiting the overlook shelter. Those users were provided an overlook of the beach and opportunities to read interpretive material presented on signs about the reserve; however, did not access the beach. The free Seymour Center docent led Younger Lagoon beach tours were temporarily suspended in March 2020 and remained so until April 2022. Since the start of the Seymour Center docent led beach access tours, 215 tours have gone out and nearly 1,400 visitors have participated. The beach access tours are part of a broad offering of public outreach and education programming on the Coastal Science Campus managed by the Seymour Center, including K-12 school visits to the Seymour Center, the Ocean Explorers Summer Camp, Bay Area Libraries Discover and Go Program, as well as print, web, social media, and radio campaigns.

Despite ongoing staff efforts towards public outreach and education, some unauthorized uses of Younger Lagoon Reserve, including trespass, theft, and vandalism occurred in FY 2021-2022. Thus far, no significant damage to ecologically sensitive habitat areas, research sites, research equipment, or facilities has occurred. Reserve staff will continue their public outreach and education efforts, and continue to partner with UCSC campus police to ensure the security of the reserve and protect sensitive resources and ongoing research.

Table 1. Younger Lagoon user affiliations.

University of California Campus	**Non-governmental Organizations**
University of California, Berkeley	Audubon Society
University of California, Davis	Black Oystercatcher Monitoring Project
University of California, Irvine	Kids in Nature
University of California, Santa Cruz	Santa Cruz Bird Club
	Seymour Marine Discovery Center
California State Universities	UC Santa Cruz Retiree Association
California State University, San Jose	
California State University, Humboldt	**Governmental Agencies**
California Polytechnic State University, San Luis Obispo	California Department of Fish and Wildlife
	Elkhorn Slough National Estuarine Research Reserve
California Community College	
Cabrillo Community College	
Other Colleges and Universities	
Santa Clara University	**K-12 Education**
Washington State University	Pacific Collegiate School

Table 2. Younger Lagoon Total Use.

RESERVE USE DATA Fiscal year: 2021-2022

Campus: University of California, Santa Cruz
Reserve: Younger Lagoon Reserve

	UC Home		UC Other		CSU System		CA Comm College		Other CA College		Out of State College		International University		Government		NGO/Non-Profit		Business Entity		K-12 School		Other		Total	
	Users	UDs	Users	UDs	Users	UDs	Users	UDs	Users	UDs	Users	UDs	Users	UDs	Users	UDs	Users	UDs	Users	UDs	Users	UDs	Users	UDs	Users	UDs
UNIVERSITY- LEVEL RESEARCH																										
Faculty	5	67	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	67
Research Scientist/Post Doc	0	0	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	2
Research Assistant (non-student/faculty/postdoc)	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
Graduate Student	3	61	2	5	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	6	67
Undergraduate Student	8	67	2	2	1	30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	11	99
Professional	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	1	1
Other	0	0	1	2	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	2	3
SUBTOTAL	16	195	7	12	1	30	0	0	0	0	1	1	0	0	1	1	1	1	0	0	0	0	0	0	27	240
UNIVERSITY - LEVEL INSTRUCTION (CLASS)																										
Staff	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
Faculty	11	20	0	0	1	2	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	13	24
Graduate Student	28	32	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	29	33
Undergraduate Student	473	1684	0	0	45	45	20	20	6	6	15	30	0	0	0	0	0	0	0	0	0	0	0	0	559	1785
Professional	1	20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	20
Volunteer	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
SUBTOTAL	514	1757	0	0	47	48	22	23	6	6	15	30	0	0	0	0	0	0	0	0	0	0	0	0	604	1864
OTHER																										
Staff	11	37	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	11	37
Faculty	4	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	5
Undergraduate Student	16	16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	16	16
K-12 Instructor	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	16	0	0	1	1	0	0	5	19
K-12 Student	50	170	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	30	48	0	0	80	218
Professional	5	5	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	6	6
Other	26	26	0	0	0	0	0	0	0	0	0	0	0	0	0	0	17	33	0	0	0	0	266	1623	309	1682
Docent	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	15	15	15	15
Volunteer	15	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	26	0	0	0	0	15	15	32	56
SUBTOTAL	129	276	0	0	0	0	0	0	0	0	0	0	0	0	1	1	21	75	0	0	31	49	296	1653	478	2054
HOUSING																										
TOTALS	**659**	**2228**	**7**	**12**	**48**	**78**	**22**	**23**	**6**	**6**	**16**	**31**	**0**	**0**	**2**	**2**	**22**	**76**	**0**	**0**	**31**	**49**	**296**	**1653**	**1109**	**4158**

Sand Plant Beach (Little Wilder)

Sand Plant Beach is located adjacent to Wilder State Park and is frequented by Wilder State Park visitors along a coastal bluff trail. Because of the size of Wilder Ranch State Park (over 7,000 acres, with over 35 miles of trails) and its multiple points of access, it is unknown exactly how many people visit Sand Plant Beach each year. However, even though it requires a hike it is one of the more popular beaches along this section of Wilder Ranch as there is relatively easy access along the coastal bluff trail. We surveyed Sand Plant Beach from FY10-11 – FY14-15.

Natural Bridges Lagoon

We did not obtain user data for Natural Reserves during the survey period; however, more than 925,000 people are estimated to have visited Natural Bridges State Park in 2005 (Santa Cruz State Parks 2010). The proportion of those visitors that use the beach and lagoon habitat is unknown. It is likely that the number of visitors remains in this range from year to year. We surveyed Natural Bridges Lagoon from FY10-11 – FY14-15.

Human Use During Survey Efforts

Although we are no longer monitoring Natural Bridges and Sand Plant beaches, we continue include results in order to have standalone reports that include all data going forward. Number of users at YLR beach during the survey efforts varied among beach as well as between sampling dates. However, the pattern of total use and the number of people per photo (15 minute interval standardized for area surveyed) was consistent across sampling periods (Table 3). Examples of photos captured during a typical monitoring session in 2010 are included as Figure 4.

Table 3. Number of people observed in photo human use monitoring.

Site	Month	[1]Total # of people	[1]Ave # of People / 15 minute
Natural Bridges	May, 2010	313	3.13
Sand Plant	May, 2010	92	1.21
Younger Lagoon	May, 2010	2	0.28
Natural Bridges	August, 2010	224	2.69
Sand Plant	August, 2010	15	0.17
Younger Lagoon	August, 2010	0	0
Natural Bridges	November, 2010	207	2.07
Sand Plant	November, 2010	7	0.17
Younger Lagoon	November, 2010	1	0.02
Natural Bridges	February, 2011	185	2.64
Sand Plant	February, 2011	10	0.25
Younger Lagoon	February, 2011	2	0.06

Site	Month	[1]Total # of people	[1]Ave # of People / 15 minute
Natural Bridges	May, 2011	236	2.8
Sand Plant	May, 2011	13	0.38
Younger Lagoon	May, 2011	5	0.18
Natural Bridges	July, 2011	795	2.44
Sand Plant	July, 2011	7	0.25
Younger Lagoon	July, 2011	0	0
Natural Bridges	December, 2011	49	0.63
Sand Plant	December, 2011	39	1.16
Younger Lagoon	December, 2011	0	0
Natural Bridges	April, 2012	442	6.93
Sand Plant	April, 2012	120	2.05
Younger Lagoon	April, 2012	0	0
Natural Bridges	May, 2012	624	2.67
Sand Plant	May, 2012	14	0.19
Younger Lagoon	May, 2012	0	0
Natural Bridges	October, 2012	210	4.84
Sand Plant	October, 2012	83	1.06
Younger Lagoon	October, 2012	3	0.04
Natural Bridges	January, 2013	100	4.90
Sand Plant	January, 2013	24	0.81
Younger Lagoon	January, 2013	9	0.11
Natural Bridges	May, 2013	615	19.81
Sand Plant	May, 2013	21	0.52
Younger Lagoon	May, 2013	0	0
Natural Bridges	July, 2013	560	25.42
Sand Plant	July, 2013	29	0.96
Younger Lagoon	July, 2013	5	0.06
Natural Bridges	November, 2013	3.44	13.04
Sand Plant	November, 2013	6	0.19
Younger Lagoon	November, 2013	12	0.15
Natural Bridges	February, 2014	71	6.37
Sand Plant	February, 2014	6	0.20
Younger Lagoon	February, 2014	1	0.01

Site	Month	[1]Total # of people	[1]Ave # of People / 15 minute
Natural Bridges	June, 2014	1723	21.01
Sand Plant	June, 2014	239	2.92
Younger Lagoon	June, 2014	2	0.02
Natural Bridges	August, 2014	852	23.68
Sand Plant	August, 2014	227	2.52
Younger Lagoon	August, 2014	2	0.02
Natural Bridges	November, 2014	2131	21.69
Sand Plant	November, 2014	146	1.78
Younger Lagoon	November, 2014	2	0.02
Natural Bridges	January, 2015	1889	23.04
Sand Plant	January, 2015	225	2.75
Younger Lagoon	January, 2015	11	0.13
Natural Bridges	April, 2015	699	7.13
Sand Plant	April, 2015	-	-
Younger Lagoon	April, 2015	0	0
Younger Lagoon	July, 2015	6	0.02
Younger Lagoon	October, 2015	0	0
Younger Lagoon	February, 2016	0	0
Younger Lagoon	May, 2016	1	0.02
Younger Lagoon	July, 2016	0	0
Younger Lagoon	November, 2016	0	0
Younger Lagoon	February, 2017	0	0
Younger Lagoon	April, 2017	0	0
Younger Lagoon	August, 2017	19	0.16
Younger Lagoon	October, 2017	6	0.05
Younger Lagoon	February, 2018	0	0
Younger Lagoon	May, 2018	27	0.22
Younger Lagoon	July, 2018	11	0.09
Younger Lagoon	November, 2018	14	0.15
Younger Lagoon	February, 2019	62	0.65
Younger Lagoon	May, 2019	0	0
Younger Lagoon	July, 2019	0	0
Younger Lagoon	November, 2019	0	0
Younger Lagoon	February, 2020	0	0
Younger Lagoon	May, 2020	0	0

Site	Month	[1]Total # of people	[1]Ave # of People / 15 minute
Younger Lagoon	August, 2020	1	.02
Younger Lagoon	November, 2020	-	-
Younger Lagoon	February, 2021	0	0
Younger Lagoon	May, 2021	0	0
Younger Lagoon	August, 2021	0	0
Younger Lagoon	November, 2021	0	0
Younger Lagoon	March, 2022	0	0
Younger Lagoon	May, 2022	0	0

[1]Standardized by area surveyed.

Figure 4. Photos captured by remote camera during the Spring 2010 monitoring effort. Top to bottom: Sand Plant Beach, Natural Bridges, and Younger Lagoon.

Photo Documentation of YLR

Photos were taken one time during each reporting period. Photos for FY2020-2021 report are included as Appendix 1.

Tidewater Goby Surveys

Although we are no longer monitoring Natural Bridges and Sand Plant beaches, we continue include results in order to have standalone reports that include all data going forward. Evidence of breeding (multiple size classes) continued to be observed at YLR during the reporting period (Table 4).

Table 4. Fish species encountered during sampling efforts.

	Tidewater Goby	Stickleback	Sculpin	Mosquito Fish	Halibut	CRLF [1]	Bluegill
April 9, 2010							
Little Wilder	X	X					
Younger Lagoon	X	X					
Natural Bridges	X	X	X				
August 13, 2010							
Little Wilder	X	X					
Younger Lagoon	X	X					
Natural Bridges	X	X	X	X			
November 18, 2010							
Little Wilder	X	X					
Younger Lagoon	X						
Natural Bridges	X	X	X	X			
February 23, 2011							
Little Wilder	X	X					
Younger Lagoon	X						
Natural Bridges	X	X	X	X			
May 12, 2011							
Little Wilder	X	X					
Younger Lagoon	X	X	X		X		
Natural Bridges	X	X	X				
August 8, 2011							
Little Wilder	X	X					
Younger Lagoon	X	X					
Natural Bridges	X	X					
December 12, 2011							
Little Wilder	X	X					
Younger Lagoon	X						
Natural Bridges	X	X					
March 8, 2012							
Little Wilder	X	X					
Younger Lagoon	X						
Natural Bridges	X	X					
May 15, 2012							
Little Wilder	X	X					
Younger Lagoon	X	X					
Natural Bridges	X	X	X				
August 29, 2012							
Little Wilder	X	X				X	

Younger Lagoon	X	X		X
Natural Bridges	X	X		
October 23, 2012				
Little Wilder	X	X		
Younger Lagoon	X	X		
Natural Bridges	X	X		
February 2, 2013				
Little Wilder	X	X		
Younger Lagoon	X	X		
Natural Bridges	X	X		
May 6, 2013				
Little Wilder	X	X		X
Younger Lagoon	X	X		X
Natural Bridges	X	X		
July 16, 2013				
Little Wilder	X	X		X
Younger Lagoon	X	X		
Natural Bridges	X	X	X	
November 14, 2013				
Little Wilder	X	X		
Younger Lagoon	X	X		
Natural Bridges				
February 21, 2014				
Little Wilder	X	X		
Younger Lagoon	X	X		
Natural Bridges	X			
May 2, 2014				
Little Wilder	X	X		
Younger Lagoon	X	X		
Natural Bridges	X			
August 11, 2014				
Little Wilder	X	X		
Younger Lagoon	X	X		
Natural Bridges	X	X		
November 25, 2014				
Little Wilder	X	X		
Younger Lagoon	X	X		
Natural Bridges	X	X		
January 26, 2015				
Little Wilder	X	X		
Younger Lagoon	X	X		

Natural Bridges	X		
April 13, 2015			
Little Wilder	X	X	
Younger Lagoon	X	X	
Natural Bridges	X	X	X
July 8, 2015			
Younger Lagoon	X	X	
November 4, 2015			
Younger Lagoon	X	X	
February 9, 2016			
Younger Lagoon	X	X	
May 13, 2016			
Younger Lagoon	X	X	
July 20, 2016			
Younger Lagoon	X	X	
November 17, 2016			
Younger Lagoon	X	X	
March 1, 2017			
Younger Lagoon			
May 3, 2017			
Younger Lagoon	X	X	
August 9, 2017			
Younger Lagoon	X	X	
November 9, 2017			
Younger Lagoon	X	X	
February 9, 2018			
Younger Lagoon	X	X	
May 2, 2018			
Younger Lagoon	X	X	
July 16, 2018			
Younger Lagoon	X	X	
November 18, 2018			
Younger Lagoon	X		
February 21, 2019			
Younger Lagoon			

May 14, 2019 Younger Lagoon	X	X				X	
August 15, 2019 Younger Lagoon	X	X					
October 31, 2019 Younger Lagoon	X	X					
February 13, 2020 Younger Lagoon	X						
May 21, 2020 Younger Lagoon	X	X					
August 19, 2020 Younger Lagoon	X	X					
November 17, 2020 Younger Lagoon	X	X					
February 24, 201 Younger Lagoon	X	X					
May 4, 2021 Younger Lagoon	X	X					
August 21, 2021 Younger Lagoon	X	X					
November 17, 2021 Younger Lagoon	X	X					
March 8, 2022 Younger Lagoon	X						
May 4, 2022 Younger Lagoon	X	X					
No. of sites	3	3	2	2	1	2	1

[1]CRLF = California Red-legged Frog (*Rana draytonii*). Tadpoles have been observed at Little Wilder. Tadpoles, juveniles, young of year, and adults have been observed at YLR and Little Wilder.

Species Composition and Coverage of Beach Dune Vegetation

Although we are no longer monitoring Natural Bridges and Sand Plant beaches, we continue include results in order to have standalone reports that include all data going forward. Evidence of reproduction (flowers, seeds, and seedlings) of native and non-native vegetation has been detected at all three sites. Distance from mean high tide to the lowest plant on the beach was consistently greatest at Natural Bridges and lowest at Sand Plant Beach and Younger Lagoon (Table 5). Plant cover was generally higher at Sand Plant and Younger Lagoon (as exhibited by proportion of bare ground) but varied across sampling efforts (Figure 5).

Native plant species richness was consistently greatest at Younger Lagoon; however, it varied across sampling periods (Figure 6). Mean proportion of non-native species also varied across sampling periods. Mean proportion of non-native species was consistently greatest at Natural Bridges (69%) and least at either Sand Plant Beach (28%) or Younger Lagoon (28%) (Table 6).

Table 5. Distance (m) from mean high tide to the lowest plant on the beach.

Site	**Spring, 10**	**Summer, 10**	**Fall, 10**	**Winter, 11**	**Spring, 11**	**Summer, 11**	**Fall, 11**	**Winter, 12**	**Spring, 12**
Younger Lagoon	56	51	20	42	55	49	26	30	28
Sand Plant Beach	33	34	56	56	40	51	29	31	38
Natural Bridges	128	130	141	146	146	138	155	160	123

Site	**Summer, 12**	**Fall, 12**	**Winter, 13**	**Spring, 13**	**Summer, 13**	**Fall, 13**	**Winter, 14**	**Spring, 14**
Younger Lagoon	47	20	30	36	37.3	32.1	26.4	36.5
Sand Plant Beach	35	38	31	41	48.1	49.9	45.6	24.2
Natural Bridges	91	75	100	72	88.9	107.3	87.4	83.2

Site	**Summer, 14**	**Fall, 14**	**Winter, 15**	**Spring, 15**	**Summer, 15**	**Fall, 15**	**Winter, 16**	**Spring, 16**
Younger Lagoon	21.4	10	26.4	19.5	19.3	20.5	31.4	42.8
Sand Plant Beach	27.5	31	24.5	29.2				
Natural Bridges	74.3	89.4	71	75.8				

Site	**Summer, 16**	**Fall, 16**	**Winter, 17**	**Spring, 17**	**Summer, 17**	**Fall, 17**	**Winter, 18**	**Spring, 18**
Younger Lagoon	36.6	46.3	19.5	37.3	22.3	39.3	32	29

Site	**Summer, 18**	**Fall, 18**	**Winter, 19**	**Spring, 19**	**Summer, 19**	**Fall, 19**	**Winter, 20**	**Spring, 20**
Younger Lagoon	28	22	23	24.7	38	26	29	27

Site	**Summer, 20**	**Fall, 20**	**Winter, 21**	**Spring, 21**	**Summer, 21**	**Fall, 21**	**Winter, 22**	**Spring, 22**
Younger Lagoon	28.3	23	24	25	23.5	22.5	21.75	28

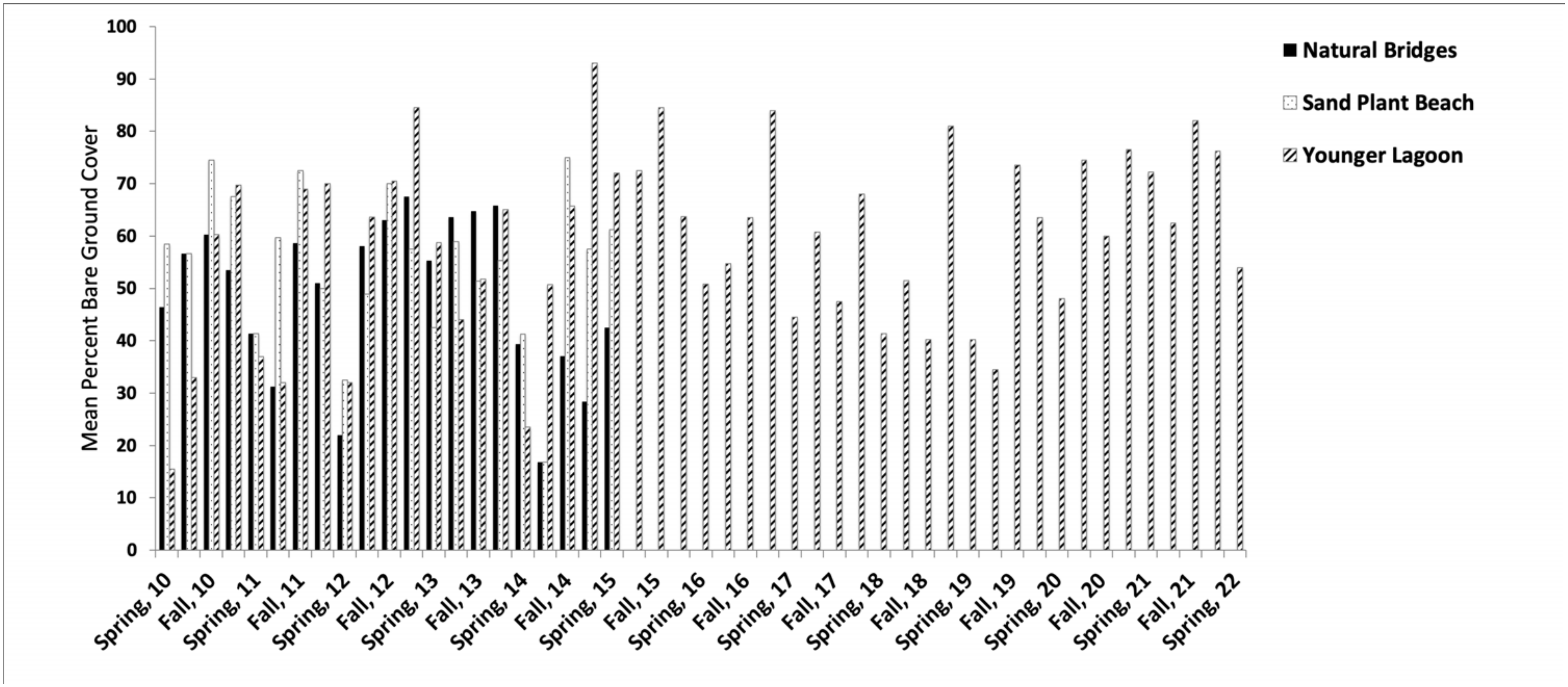

Figure 5. Mean percent bare ground encountered at each site.

Table 6. Number and proportion of native and non-native plant species encountered during surveys. Mean is calculated across all samples.

Site	Spring, 10	Summer, 10	Fall, 10	Winter, 11	Spring, 11	Summer, 11	Fall, 11	Winter, 12	Spring, 12
Natural Bridges									
Native	7 (41%)	8 (44%)	9 (60%)	8 (44%)	9 (43%)	6 (67%)	8 (62%)	9 (47%)	11 (48%)
Non-native	10 (59%)	10 (56%)	5 (40%)	10 (66%)	12 (57%)	9 (33%)	5 (38%)	10 (53%)	12 (52%)
Total	17	18	14	18	21	15	13	19	23
Younger Lagoon									
Native	11 (85%)	11 (85%)	11 (85%)	11 (73%)	12 (80%)	13 (81%)	9 (82%)	6 (50%)	6 (43%)
Non-native	2 (15%)	2 (15%)	2 (15%)	4 (27%)	3 (20%)	3 (19%)	2 (18%)	6 (50%)	8 (57%)
Total	13	13	13	15	15	16	11	12	14
Sand Plant Beach									
Native	7 (88%)	7 (63%)	7 (70%)	8 (80%)	7 (88%)	7 (88%)	9 (82%)	3 (33%)	4 (40%)
Non-native	1 (12%)	2 (37%)	3 (30%)	2 (20%)	1 (12%)	1 (12%)	2 (18%)	6 (67%)	6 (60%)
Total	8	9	10	10	8	8	11	9	10

Site	Summer, 12	Fall, 12	Winter, 13	Spring, 13	Summer, 13	Fall, 13	Winter, 14	Spring, 14
Natural Bridges								
Native	5 (35%)	10 (59%)	7 (88%)	9 (56%)	7 (37%)	6 (35%)	6 (43%)	10 (50%)
Non-native	9 (65%)	7 (41%)	8 (12%)	6 (44%)	12 (63%)	11 (65%)	8 (57%)	10 (50%)
Total	14	17	15	16	19	17	14	20
Younger Lagoon								
Native	12 (67%)	7 (88%)	9 (69%)	12 (75%)	13 (72%)	14 (74%)	10 (83%)	12 (67%)
Non-native	6 (33%)	1 (12%)	4 (31%)	4 (25%)	5 (28%)	5 (26%)	2 (17%)	6 (33%)
Total	18	8	13	16	18	19	12	18
Sand Plant Beach								
Native	2 (40%)	3 (50%)	4 (100%)	4 (67%)	6 (100%)	6 (100%)	5 (100%)	5 (83%)
Non-native	3 (60%)	3 (50%)	0 (0%)	2 (33%)	0 (0%)	0 (0%)	0 (0%)	1 (17%)

Total	5	6	4	6	6	6	5	6

Site	Summer, 14	Fall, 14	Winter, 15	Spring, 15	Summer, 15	Fall, 15	Winter, 16	Spring 16
Natural Bridges								
Native	5 (42%)	5 (45%)	4 (33%)	5 (31%)				
Non-native	7 (58%)	6 (55%)	8 (67%)	11 (69%)				
Total	12	11	12	16				
Younger Lagoon								
Native	9 (69%)	5 (62%	10 (67%)	10 (67%)	11 (73%)	2 (67%)	5 (100%)	10 (83%)
Non-native	4 (31%)	3 (38%)	5 (33%)	5 (33%)	4 (27%)	1 (33%)	0 (0%)	2 (17%)
Total	13	8	15	15	15	3	5	12
Sand Plant Beach								
Native	4 (50%)	4 (40%)	5 (50%)	4 (33%)				
Non-native	4 (50%)	6 (60%)	5 (50%	8 (67%)				
Total	8	10	10	12				

Site	Summer, 16	Fall, 16	Winter, 17	Spring, 17	Summer, 17	Fall, 17	Winter, 18	Spring, 18
Younger Lagoon								
Native	10 (83%)	8 (57%)	3 (60%)	13 (68%)	12 (70%)	13 (76%)	12 (70%)	9 (82%)
Non-native	2 (17%)	6 (43%)	2 (40%)	6 (32%)	5 (30%)	4 (24%)	5 (30%)	2 (18%)
Total	12	14	5	19	17	17	17	11

Site	Summer, 18	Fall, 18	Winter, 19	Spring, 19	Summer, 19	Fall, 19	Winter, 20	Spring, 20
Younger Lagoon								
Native	9 (82%)	8 (80%)	8 (80%)	9 (67%)	8 (67%)	8 (67%)	8 (57%)	9 (53%)
Non-native	2 (18%)	2 (20%)	2 (20%)	3 (33%)	4 (33%)	4 (33%)	6 (43%)	8 (47%)
Total	11	10	10	12	12	14	14	17

Site	Summer, 20	Fall, 20	Winter, 21	Spring, 21	Summer, 21	Fall, 21	Winter, 22	Spring, 22
Younger Lagoon								
Native	6 (67%)	8 (73%)	7 (58%)	7 (58%)	6 (67%)	7 (78%)	6 (75%)	6 (67%)

Non-native	3 (33%)	3 (27%)	5 (42%)	5 (42%)	3 (33%)	2 (22%)	2 (25%)	3 (33%)
Total	9	11	12	12	9	9	8	9

Site	Proportion of native and non-native species across all sample periods
Natural Bridges	
Native	**47%**
Non-native	**53%**
Total	
Younger Lagoon	
Native	**72%**
Non-native	**28%**
Total	
Sand Plant Beach	
Native	**72%**
Non-native	**28%**
Total	

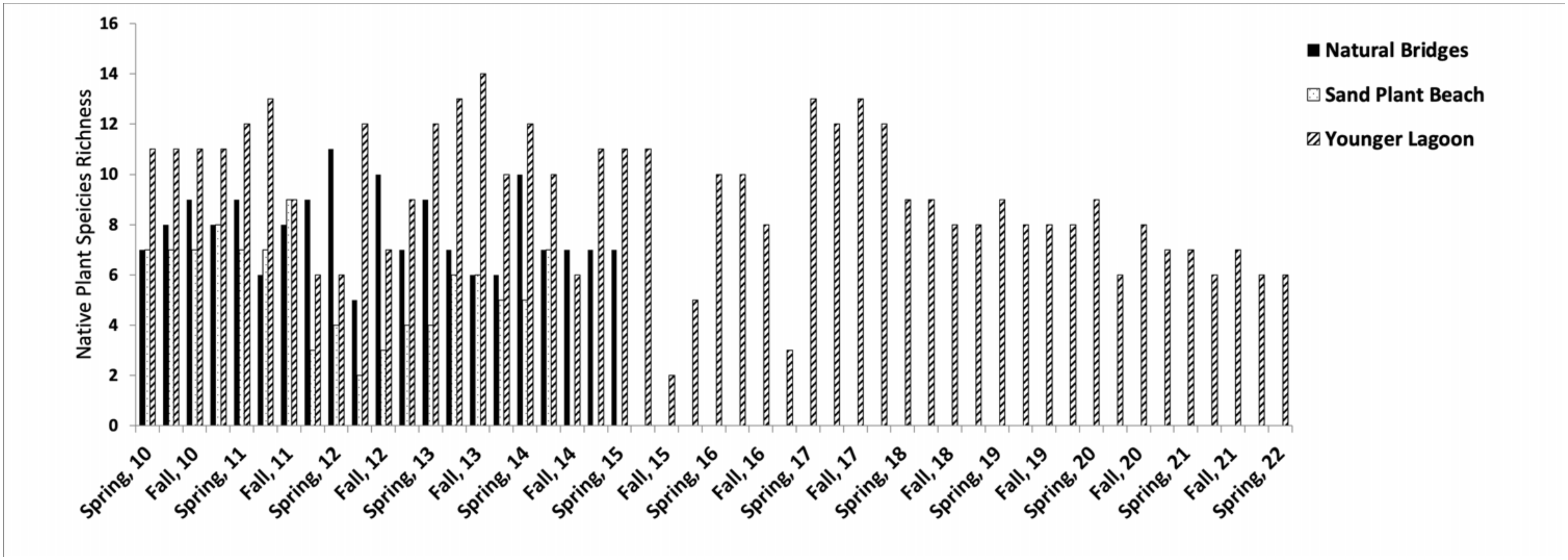

Figure 6. Number of native plant species encountered at each site.

Track Plate Monitoring

Although we are no longer monitoring Natural Bridges and Sand Plant beaches, we continue include results in order to have standalone reports that include all data going forward. Native species richness of mammals detected in raked sand plots was across all three sites (n = 8). Ground squirrel were not detected at Natural Bridges and opossum have not been detected in our track surveys at Sand Plant Beach or Younger Lagoon Reserve (Table 7). It is likely that ground squirrels occur at Natural Bridges and opossum are likely using upland habitat at Sand Plant Beach and Younger Lagoon Reserve; however, they were not detected in our survey efforts. Dogs and bicycles were detected at Natural Bridges and Sand Plant Beach and vehicles were detected at Natural Bridges (Table 7). For the first time since sampling began in 2010, no bobcats were detected at Younger Lagoon Reserve in FY2019-2020, while humans were detected during every sampling event. Perhaps due to the decrease in human use due to the pandemic, in FY2020-2021, bobcats were once again detected and no humans were detected during sampling events. Frequency of detection and species richness for each species is summarized in Table 8.

Table 7. Summary of track plate sampling effort at each site.

	Rodent[1]	Raccoon	Cottontail	Bobcat	Skunk	Squirrel	Deer	Opossum	Coyote	Bicycle	Vehicle	Dog	Human
May 1-2, 2010													
Little Wilder	X			X	X	X			X	X			X
Younger Lagoon	X	X		X	X								X
Natural Bridges	X	X		X	X				X	X	X	X	X
August 11-12, 2010													
Little Wilder		X		X	X							X	X
Younger Lagoon	X	X	X	X		X							
Natural Bridges	X	X	X									X	X
November 17-18, 2010													
Little Wilder	X		X	X					X				X
Younger Lagoon	X	X											X
Natural Bridges	X	X		X							X	X	X
February 8 -9, 2011													
Little Wilder	X			X	X				X	X			X
Younger Lagoon	X	X			X				X				
Natural Bridges		X		X					X		X		X

	Rodent[1]	Raccoon	Cottontail	Bobcat	Skunk	Squirrel	Deer	Opossum	Coyote	Bicycle	Vehicle	Dog	Human
May 3 - 4, 2011													
Little Wilder	X		X	X									
Younger Lagoon		X	X	X	X				X				
Natural Bridges		X			X				X			X	X
July 22 - 23, 2011													
Little Wilder	X	X			X				X				X
Younger Lagoon	X	X	X	X	X								
Natural Bridges	X	X	X		X							X	X
March 8 - 9, 2012													
Little Wilder	X								X				X
Younger Lagoon				X					X				
Natural Bridges							X				X	X	X
May 15 - 16, 2012													
Little Wilder	X		X	X									X
Younger Lagoon	X	X		X					X				
Natural Bridges	X			X				X				X	X
August 16 - 17, 2012													
Little Wilder	X	X	X	X	X		X		X				X
Younger Lagoon	X	X		X		X	X						
Natural Bridges	X	X	X	X	X		X				X	X	X
October 22 - 23, 2012													
Little Wilder	X						X		X				X
Younger Lagoon		X		X					X				X
Natural Bridges			X		X		X				X		X
January 16 -17, 2013													
Little Wilder	X			X					X				X
Younger Lagoon	X	X		X					X				X
Natural Bridges		X		X	X				X			X	X
May 15 - 16, 2013													

	Rodent[1]	Raccoon	Cottontail	Bobcat	Skunk	Squirrel	Deer	Opossum	Coyote	Bicycle	Vehicle	Dog	Human
Little Wilder	X			X	X								X
Younger Lagoon	X	X		X					X				X
Natural Bridges	X	X			X							X	X
July 18 - 19, 2013													
Little Wilder	X	X		X					X			X	X
Younger Lagoon	X	X		X					X				
Natural Bridges		X		X	X						X	X	X
October 21- 22, 2013													
Little Wilder		X		X									
Younger Lagoon		X		X					X				X
Natural Bridges	X	X			X				X		X	X	X
February10-11, 2014													
Little Wilder	X	X		X									X
Younger Lagoon									X				X
Natural Bridges		X			X						X		X
April 27-28, 2014													
Little Wilder		X		X					X				X
Younger Lagoon		X							X				
Natural Bridges		X		X	X						X	X	X
July 30-31, 2014													
Little Wilder		X		X					X				X
Younger Lagoon		X		X					X				
Natural Bridges		X			X		X		X		X	X	X
November 4-5, 2014													
Little Wilder				X					X			X	X
Younger Lagoon		X		X					X				
Natural Bridges		X					X				X		X
January 26-27, 2015													
Little Wilder	X								X				X
Younger Lagoon	X	X		X			X						X

	Rodent[1]	**Raccoon**	**Cottontail**	**Bobcat**	**Skunk**	**Squirrel**	**Deer**	**Opossum**	**Coyote**	**Bicycle**	**Vehicle**	**Dog**	**Human**
Natural Bridges	X				X		X		X		X	X	X
April 14-15, 2015													
Little Wilder	X	X							X				X
Younger Lagoon	X	X		X					X				
Natural Bridges	X				X		X		X		X	X	X
July 8-9, 2015													
Younger Lagoon	X			X	X								
									X				X
October 29-30, 2015													
Younger Lagoon		X		X									
February 2-3, 2016													
Younger Lagoon		X							X				
May3-4, 2016													
Younger Lagoon		X							X				
July 12-13, 2016													
Younger Lagoon		X		X									
November 9-10, 2016													
Younger Lagoon		X		X					X				
March 1-2, 2017													
Younger Lagoon	X	X		X									
April 25-26, 2017													
Younger Lagoon		X					X		X				X
August 2-3, 2017													
Younger Lagoon					X				X				
October 25-26, 2017													
Younger Lagoon		X					X		X	X			X

	Rodent[1]	Raccoon	Cottontail	Bobcat	Skunk	Squirrel	Deer	Opossum	Coyote	Bicycle	Vehicle	Dog	Human
February 7-8, 2018													
Younger Lagoon	X			X	X								X
May 1-2, 2018													
Younger Lagoon	X								X				
July 12-13, 2018													
Younger Lagoon	X			X					X				X
November 7-8, 2018													
Younger Lagoon	X	X					X		X				X
February 20-21, 2019													
Younger Lagoon	X	X							X				
May 15-16, 2019													
Younger Lagoon	X			X					X				X
July 15-16, 2019													
Younger Lagoon		X											X
October 29-30, 2019													
Younger Lagoon													X
February 11-12, 2020													
Younger Lagoon		X							X				X
May 20-21, 2020													
Younger Lagoon		X											X
August 18-19, 2020													
Younger Lagoon													
Nov 16-17, 2020													
Younger Lagoon				X									

	Rodent[1]	Raccoon	Cottontail	Bobcat	Skunk	Squirrel	Deer	Opossum	Coyote	Bicycle	Vehicle	Dog	Human
February 22-23, 2021													
Younger Lagoon				X			X		X				
May 4-5, 2021													
Younger Lagoon				X			X		X				
August 10-11, 2021													
Younger Lagoon				X					X				X
Nov 16-17, 2021													
Younger Lagoon		X		X									X
February 7-8, 2022													
Younger Lagoon	X								X				X
May 3-4, 2022													
Younger Lagoon							X		X				
	3	3	3	3	3	2	3	1	3	3	1	2	3

[1]Unidentified small rodent.

Table 8. Frequency of occurrence, and native species richness, of animals and human use types through spring 2022 track plate sampling efforts. Actual detections are included parenthetically.

Site	Rodent	Raccoon	Cottontail	Bobcat	Skunk	Squirrel	Deer	Opossum	Coyote	Bicycle	Vehicle	Dog	Human	[1]Native sp. Richness
Little Wilder	(15) 71%	(10) 48%	(4) 19%	(15) 71%	(6) 29%	(1) 6%	(2) 10%	0%	(15) 71%	(2) 10%	(0) 0%	(3) 14%	(19) 91%	8
Younger Lagoon	(22) 48%	(27) 60%	(2) 4%	(30) 67%	(9) 20%	(2) 4%	(8) 16%	0%	(32) 71%	(1) 2%	(0) 0%	(0) 0%	(22) 45%	8
Natural Bridges	(9) 43%	(15) 71%	(4) 19%	(9) 43%	(13) 62%	0%	(8) 38%	(1) 5%	(9) 43%	(1) 5%	(14) 67%	(16) 76%	(21) 100%	8

[1]Bicycle, vehicle, dog, and human excluded.

Small Mammal Trapping

Although we are no longer monitoring Natural Bridges and Sand Plant beaches, we continue include results in order to have standalone reports that include all data going forward. A total of 347 individual small mammals representing four species have been captured during small mammal trapping efforts (Table 9).

Table 9. Summary of Sherman trapping efforts

Site	Pema[1]	Mica[1]	Reme[1]	Rara[1,2]	**TOTAL**
April 24 -25, 2010					
Little Wilder	8	5			**13**
Younger Lagoon	2				**2**
Natural Bridges			3		**3**
August 11-12, 2010					
Little Wilder	5	4			**9**
Younger Lagoon			1		**1**
Natural Bridges					**0**
November 15-16, 2010					
Little Wilder	5	1			**6**
Younger Lagoon				1	**1**
Natural Bridges		3	1		**4**
February 15-16, 2011					
Little Wilder	5				**5**
Younger Lagoon	6	5	0		**11**
Natural Bridges			2		**2**
April 29-30, 2011					
Little Wilder	4				**4**
Younger Lagoon	1				**1**
Natural Bridges					**0**
August 8-9, 2011					
Little Wilder	6	2			**8**
Younger Lagoon	3		3		**6**
Natural Bridges		1	5		**6**

Site	Pema[1]	Mica[1]	Reme[1]	Rara[1,2]	**TOTAL**
March 30, 2012					
Little Wilder	6				**6**
Younger Lagoon	1		1		**2**
Natural Bridges		5	2		**7**
May 15-16, 2012					
Little Wilder	4	1			**5**
Younger Lagoon	3				**3**
Natural Bridges		5			**5**
August 25-26, 2012					
Little Wilder	4				**4**
Younger Lagoon	3				**3**
Natural Bridges		4	2		**6**
November 5-6, 2013					
Little Wilder	2		1		**3**
Younger Lagoon	3				**3**
Natural Bridges		3	1		**4**
January 13-14, 2013					
Little Wilder	2		4		**6**
Younger Lagoon	2				**2**
Natural Bridges		2	1		**3**
May 1-2, 2013					
Little Wilder	1		1		**2**
Younger Lagoon	3		2		**5**
Natural Bridges		5			**5**
July 16-17, 2013					
Little Wilder	3		1		**4**
Younger Lagoon	1				**1**
Natural Bridges			1		**1**
October 22-23, 2013					
Little Wilder	5	1		1	**7**
Younger Lagoon	1				**1**

Site	Pema[1]	Mica[1]	Reme[1]	Rara[1,2]	**TOTAL**
Natural Bridges		1	2		**3**
February 12-13, 2014					
Little Wilder	2	1	1		**4**
Younger Lagoon	1		1		**2**
Natural Bridges		2			**2**
April 28-29, 2014					
Little Wilder	4	1			**5**
Younger Lagoon	3		1		**4**
Natural Bridges	1				**1**
July 30-31, 2014					
Little Wilder	1	1			**2**
Younger Lagoon	2				**2**
Natural Bridges	1		1		**2**
November 4-5, 2014					
Little Wilder	3	1			**4**
Younger Lagoon	4				**4**
Natural Bridges	2	1	3		**6**
January 26-27, 2015					
Little Wilder	3		1		**4**
Younger Lagoon	4		5		**9**
Natural Bridges			3		**3**
April 14-15, 2015					
Little Wilder	2		3		**5**
Younger Lagoon	3				**3**
Natural Bridges					**0**
July 8-9, 2015					
Younger Lagoon	7		1		**8**

October 29-30, 2015				
Younger Lagoon	2	6		**8**
February 2-3, 2016				
Younger Lagoon		6		**6**
May 3-4, 2016				
Younger Lagoon		3	1	**4**
July 12-13, 2016				
Younger Lagoon		4		**4**
November 9-10, 2016				
Younger Lagoon	2	1		**3**
March 1-2, 2017				
Younger Lagoon	2	1		**3**
April 25-26, 2017				
Younger Lagoon		1		**1**
August 2-3, 2017				
Younger Lagoon				**0**
October 25-26, 2017				

Younger Lagoon	1	1	2		**4**
February 8-9, 2018					
Younger Lagoon	2				**2**
May 1-2, 2018					
Younger Lagoon	1		2		**3**
July 12-13, 2018					
Younger Lagoon	6				**6**
November 7-8, 2018					
Younger Lagoon	7		2		**8**
February 20-21, 2019					
Younger Lagoon	5		2	1	**8**
May 14-15, 2019					
Younger Lagoon	4				**4**
July 15-16, 2019					
Younger Lagoon	4				**4**
October 30-31, 2019					
Younger Lagoon	1		1		**2**

February 11-12, 2020			
Younger Lagoon	2	1	**3**
May 20-21, 2020			
Younger Lagoon	1	2	**3**
August 18-19, 2020			
Younger Lagoon	6		**6**
November 16-17, 2020			
Younger Lagoon	6	2	**8**
February 23-24, 2021			
Younger Lagoon	6	2	**8**
May 4-5, 2021			
Younger Lagoon	5		**5**
August 10-11, 2021			
Younger Lagoon	1		**1**
November 16-17, 2021			
Younger Lagoon	5		**5**

Site	Pema[1]	Mica[1]	Reme[1]	Rara[1,2]	**TOTAL**
February 8-9, 2022					
Younger Lagoon	5				**5**
May 3-4, 2022					
Younger Lagoon	7				**7**
TOTAL	**218**	**56**	**92**	**4**	**370**

[1]Pema = *Peromyscus maniculatus*; Mica = *Microtus californicus*; Rema = *Reithrodontomys megalotis*; Rara = *Rattus norvegicus.* [2]Escaped before positive ID; however, suspected to be Norway Rat.

Invertebrate Monitoring

Although we are no longer monitoring Natural Bridges and Sand Plant beaches, we continue include results in order to have standalone reports that include all data going forward. Over all, Younger Lagoon consistently had the greatest number of individuals captured; however, patterns of species richness varied among sampling sessions (Figures 7-8). This may have been at least partially due to trapping methodology and disturbance as raccoons and perhaps coyote disturbed sample cups during some of the sampling efforts. Individuals were identified as distinct taxa; however, at the time of the writing of this report they have not been taxonomically keyed out.

Avian Surveys

Although we are no longer monitoring Natural Bridges and Sand Plant beaches, we continue include results in order to have standalone reports that include all data going forward. Avian species varied among sites and sampling dates (Table 10); however, number of species and abundance were consistently greatest at Natural Bridges and Younger Lagoon.

Figure 7. Species richness of invertebrates across all beaches

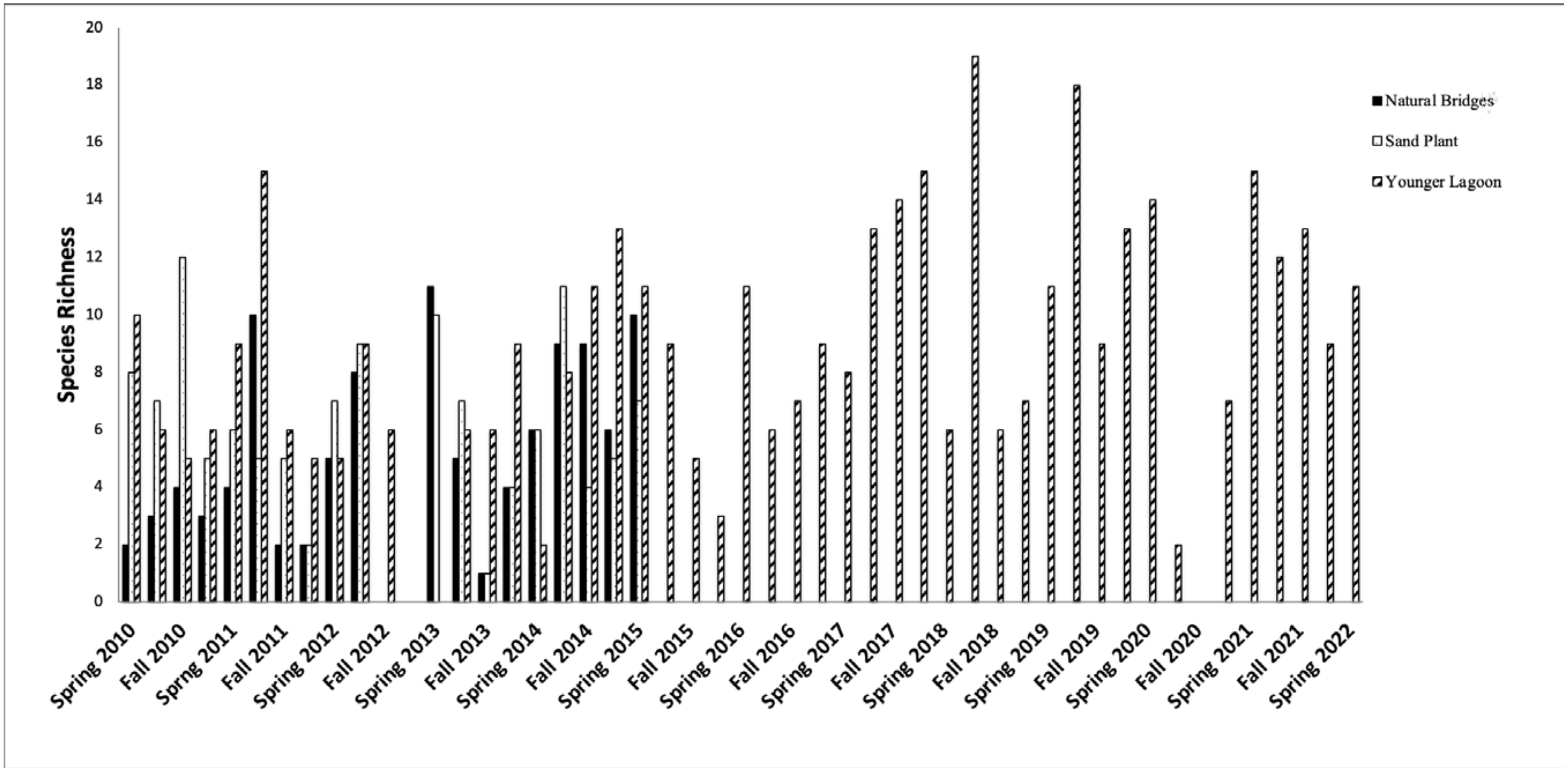

Figure 8. Total abundance of invertebrates at Natural Bridges, Sand Plant Beach, and Younger Lagoon beaches.

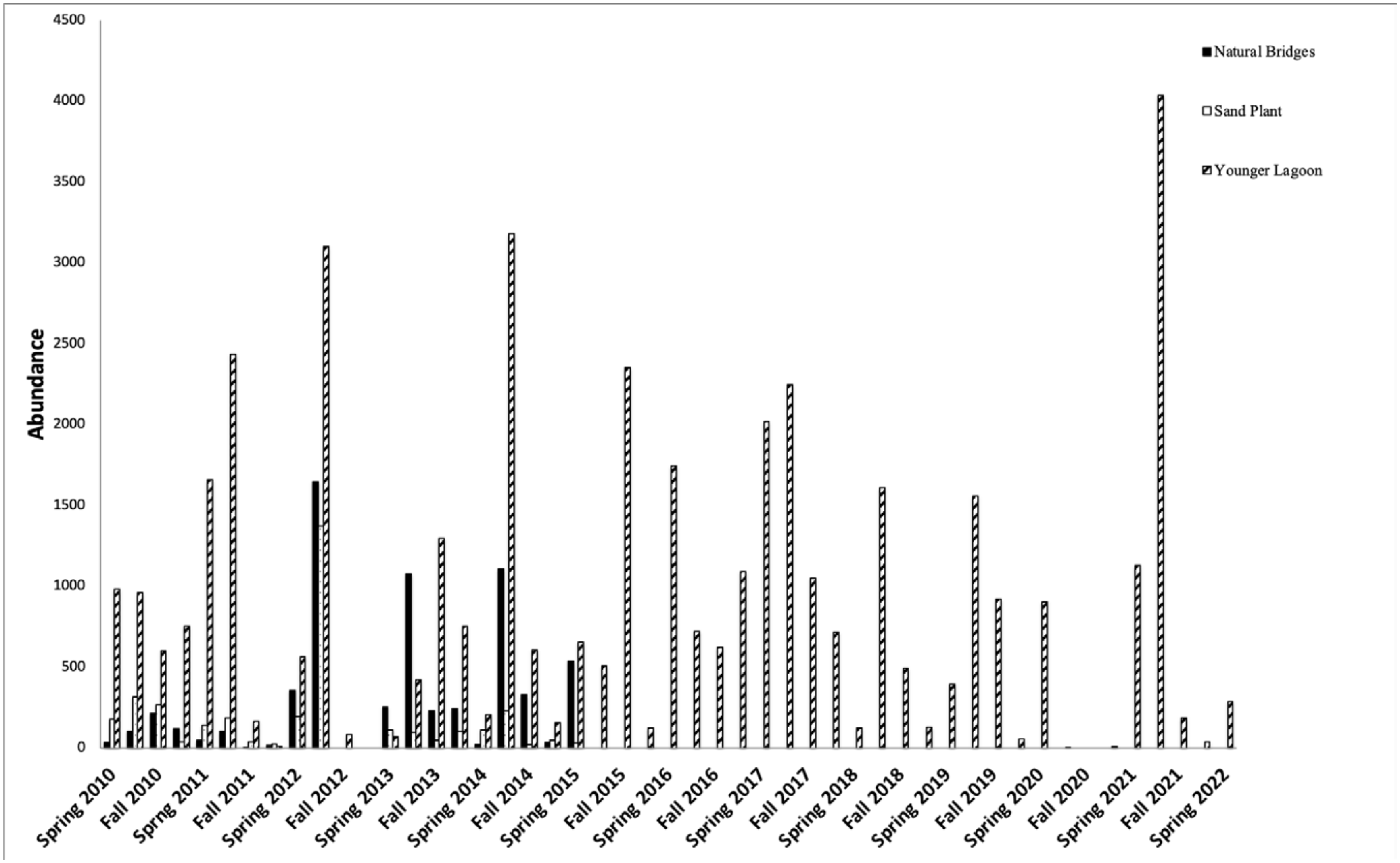

Table 10. Summary of bird surveys at Sand Plant Beach, Younger Lagoon, and Natural Bridges beaches.

Site	AMCO	AMCR	AMPE	AMWI	ANHU	BBPL	BEWR	BCNH	BASP	BASW	BLOY	BLPH	BLTU	BRAC	BRBL	BRPE	BUFF	BUHE	BUSH	CAGO	CAGU	CISW	COMU	CORA	COOT	COYE	DOCO	DUSP	EUST	FOSP	GCSP	GRHE	GREG	GRTE	HEGU
April 24 & 26, 2010																																			
Sand Plant																																			
Younger Lagoon																																			
Natural Bridges															2																				
August 11-12, 2010																																			
Sand Plant																																			1
Younger Lagoon											2																1		1						2
Natural Bridges		2													19																				
November 15 & 16, 2010																																			
Sand Plant																																3			
Younger Lagoon													1			27									2			3	1						
Natural Bridges															1																	2	2		24
February 15 & 16, 2011																																			
Sand Plant																																			
Younger Lagoon																											5								
Natural Bridges		3													2			1			58														
May 3 & 4, 2011																																			
Sand Plant		2														8																			
Younger Lagoon																																			
Natural Bridges		1										1									3						6						1		
July 22 & 23, 2011																																			
Sand Plant										4		1										4													8
Younger Lagoon																																			
Natural Bridges		9								4					6												10								48
March 29 & 30, 2012																																			
Sand Plant																					1														
Younger Lagoon															5										3				2						
Natural Bridges													1																					2	
May 15 & 16, 2012																																			
Sand Plant																																			
Younger Lagoon											3				2														2						
Natural Bridges		1													1																				
August 28 & 29, 2012																																			
Sand Plant																					2			2											
Younger Lagoon			1								1	1									4														
Natural Bridges																					1														
November 5& 6, 2012																																			
Sand Plant																									5										
Younger Lagoon															4										8										
Natural Bridges		2																																	
January 13&14, 2013																																			
Sand Plant																																			
Younger Lagoon											1							1							5										
Natural Bridges																								1								1			
May 1 & 2, 2013																																			
Sand Plant																																			
Younger Lagoon															1					2									2						
Natural Bridges		2																															2		
July 16-17, 2013																																			
Sand Plant								1													1			1											
Younger Lagoon								1				2			7						2											1			
Natural Bridges												2			1						1											1			11
October 22-23, 2013																																			
Sand Plant																					1			2											
Younger Lagoon						3						3									2						1		1						300
Natural Bridges		2				1										1					3														3
February 13-14, 2014																																			
Sand Plant																				6															
Younger Lagoon																																	1		
Natural Bridges		1																																	
April 27-28, 2014																																			
Sand Plant		3														20																			
Younger Lagoon											8					13				2															
Natural Bridges		3									2					11					7	2					8						1		
July 30-31, 2014																																			
Sand Plant																					10												1		10
Younger Lagoon																18																	4		
Natural Bridges																18																			15
November 4-5, 2014																																			
Sand Plant																									2										6
Younger Lagoon												2				5									6										
Natural Bridges		11													2										10								1		9
January 26-27, 2015																																			
Sand Plant												2								2															
Younger Lagoon																6									9										
Natural Bridges		12										1				27								3									1		
April 14-15, 2015																																			
Sand Plant												1								2					1										
Younger Lagoon												2													1										
Natural Bridges																6									7										
July 8-9, 2015																																			
Younger Lagoon								2		4																									
October 29-30, 2015																																			
Younger Lagoon												1				4					2														
February 2-3, 2016																																			
Younger Lagoon												1																	2						
May 3-4, 2016																																			
Younger Lagoon										4		2								2															1
July 12, 2016																																			
Younger Lagoon										3		1			12						2												1		
November 9-10, 2016																																			
Younger Lagoon												2				1																	1		

Site	AMCO	AMCR	AMPE	AMWI	ANHU	BBPL	BEWR	BCNH	BASP	BASW	BLOY	BLPH	BLTU	BRAC	BRBL	BRPE	BUFF	BUHE	BUSH	CAGO	CAGU	CLSW	COMU	CORA	COOT	COYE	DOCO	DUSP	EUST	FOSP	GCSP	GRHE	GREG	GRTE	HEGU
March 1-2, 2017																																			
Younger Lagoon												1									3												1		
April 25-26, 2017																																			
Younger Lagoon		1																				6							2						
August 2-3, 2017																																			
Younger Lagoon										8	2	2		8																			1		2
October 25-26, 2017																																			
Younger Lagoon												1		6		2																			
February 7-8, 2018																																			
Younger Lagoon												1		2		2															1				3
May 2-3, 2018																																			
Younger Lagoon										5	2	2		5	1																				
August 13-14, 2018																																			
Younger Lagoon										6					2						1												3		
November 7-8, 2018																																			
Younger Lagoon							1					11		29		40			1												1				
February 20-21, 2019																																			
Younger Lagoon	4											2							12	4						1									
May 14-15, 2019																																			
Younger Lagoon										4					2						2	52							1						
July 16-17, 2019																																			
Younger Lagoon										4		2									6	17		1									1		
October 30-31, 2019																																			
Younger Lagoon																																			
February 12-13, 2020																																			
Younger Lagoon	3											4						1	5		5									1					
May 20-21, 2020																																			
Younger Lagoon										30										8	2	8		2											
August 18-19, 2020																																			
Younger Lagoon										45		1		2								30	1												1
November 16-17, 2020																																			
Younger Lagoon												1		40																			1		2
February 23-24, 2021																																			
Younger Lagoon	3			2								1		7						2															
May 3-4, 2021																																			
Younger Lagoon										4										8		14		1									1		
August 10-11, 2021																																			
Younger Lagoon												2												2									3		1
November 16-17, 2021																																			
Younger Lagoon											2	2		17										2							2				1
February 8-9, 2022																																			
Younger Lagoon	3				1						2			70			1			3				2											
May 3-4, 2022																																			
Younger Lagoon									2	10		2		90		27				6	27	3		4									1		

Site	HETH	HOFI	KILL	LBCU	LESA	LISP	LOCU	MALL	MAGO	MEGU	MODO	NOHA	PECO	PEFA	PIGR	PIGU	REHA	REPH	RWBB	RODO	SAND	SAPH	SNEG	SOSP	SPSA	SSHA	SURF	VGSW	WCSP	WEGU	WESA	WHIM	YRWA	Richness
April 24 & 26, 2010																																		
Sand Plant								2																						2				1
Younger Lagoon								3															2							2				3
Natural Bridges			1															2					2											2
August 11-12, 2010																																		
Sand Plant																																		1
Younger Lagoon			2				1	10															4							32				9
Natural Bridges			1																											3				5
November 15 & 16, 2010																																		
Sand Plant																														1				2
Younger Lagoon													15								11				1					4				9
Natural Bridges			4							2											140		1		1					17		1		11
February 15 & 16, 2011																																		
Sand Plant								2																						6				2
Younger Lagoon																						1												2
Natural Bridges							3	4					47										18							6		19		10
May 3 & 4, 2011																																		
Sand Plant								4				2				35														5		1		7
Younger Lagoon																																		0
Natural Bridges			7				4	4	1											1										16		7		12
July 22 & 23, 2011																																		
Sand Plant																17							1							1				7
Younger Lagoon																																		0
Natural Bridges								7								3				2			2							81		1		11
March 29 & 30, 2012																																		
Sand Plant								5																										2
Younger Lagoon			1					8					13										2							16		2		9
Natural Bridges								10	3							2					65		2							10		5		9
May 15 & 16, 2012																																		
Sand Plant																														4		5		2
Younger Lagoon			3					2					25			5				1			2							15				10
Natural Bridges								6															2											4
August 25 & 26, 2012																																		
Sand Plant			3																															3
Younger Lagoon								4					35					8		1			1							7				10
Natural Bridges			5					1																	1					5	1			6
November 5& 6, 2012																																		
Sand Plant																														1				2
Younger Lagoon			5										14				1			4			2							3		10		9
Natural Bridges			4					9															2		1		2					12		7
January 13&14, 2013																																		
Sand Plant																																		0
Younger Lagoon													3		1						38	1	1											8
Natural Bridges																							1							11				4
May 1 & 2, 2013																																		
Sand Plant																8														2				2
Younger Lagoon								3			2		9																	11		2		8
Natural Bridges								4																						23		2		5
July 16-17, 2013																																		
Sand Plant																7																		4
Younger Lagoon			2					25					8			1							4											10
Natural Bridges			1																											10				7
October 22-23, 2013																																		
Sand Plant																																		2
Younger Lagoon			4						1				33										3							150		26		13
Natural Bridges								2															4							110		24		8
February 13-14, 2014																																		
Sand Plant								2												1										108				4
Younger Lagoon													8										4							7		10		5
Natural Bridges								2															1							19		24		5
April 27-28, 2014																																		
Sand Plant								6								4														24		2		6
Younger Lagoon			3					6								8			1											2		2		9
Natural Bridges			1					4																						18		7		11
July 30-31, 2014																																		
Sand Plant			4													3														25		2		8
Younger Lagoon			2					2								3							3							28		1		8
Natural Bridges			3																		7									80		7		6
November 4-5, 2014																																		
Sand Plant																			2											3				4
Younger Lagoon																					11		1							10		8		7
Natural Bridges			4																		20		4		1					18				10
January 26-27, 2015																																		
Sand Plant								2																						25				4
Younger Lagoon								4											10											27		1		7
Natural Bridges								2											9				2							175		3		10
April 14-15, 2015																																		
Sand Plant								2								3														5				6
Younger Lagoon			1																5				2							5				6
Natural Bridges																			4				3							21		9		7
July 8-9, 2015																																		
Younger Lagoon			2					2								4							2							31				7
October 29-30, 2015																																		
Younger Lagoon																														6				4
February 2-3, 2016																																		
Younger Lagoon								3								2							3							9		4		7
May 3-4, 2016																																		
Younger Lagoon			1					3											1						1					8				10
July 12, 2016																																		
Younger Lagoon								3															1							2				7
November 9-10, 2016																																		
Younger Lagoon			6																5											6				8

Site	HETH	HOFI	KILL	LBCU	LESA	LISP	LOCU	MALL	MAGO	MEGU	MODO	NOHA	PECO	PEFA	PIGR	PIGU	REHA	REPH	RWBB	RODO	SAND	SAPH	SNEG	SOSP	SPSA	SSHA	SURF	VGSW	WCSP	WEGU	WESA	WHIM	YRWA	Richness
March 1-2, 2017																																		
Younger Lagoon													1						6				1							2		1		10
April 25-26, 2017																																		
Younger Lagoon								4											2											2		4		8
August 2-3, 2017																																		
Younger Lagoon		6	1																															8
October 25-26, 2017																																		
Younger Lagoon			6																				1		1					10				7
February 7-8, 2018																																		
Younger Lagoon			6																7											3				8
May 2-3, 2018																																		
Younger Lagoon			4																9													2		8
August 13-14, 2018																																		
Younger Lagoon					3			1					5										4							5				9
November 7-8, 2018																																		
Younger Lagoon			6											1								1	1							75				11
February 20-21, 2019																																		
Younger Lagoon		1						4			2											2	2	1						3			2	13
May 14-15, 2019																																		
Younger Lagoon			1					15			3		1								1			3				5						12
July 16-17, 2019																																		
Younger Lagoon																3								3										8
October 30-31, 2019																																		
Younger Lagoon			3										52									1								2				4
February 12-13, 2020																																		
Younger Lagoon	2										2	2	17									2	1	4										13
May 20-21, 2020																																		
Younger Lagoon								3				1	2										1	1										10
August 18-19, 2020																																		
Younger Lagoon			11					4			1												6	2						1				12
November 16-17, 2020																																		
Younger Lagoon			8									1																		5				7
February 23-24, 2021																																		
Younger Lagoon			1																				1							1				8
May 3-4, 2021																																		
Younger Lagoon								5															3	11						1				8
August 10-11, 2021																																		
Younger Lagoon						1																	2			1				3				8
November 16-17, 2021																																		
Younger Lagoon																						1		3					4	21				12
February 8-9, 2022																																		
Younger Lagoon			4					2																1						2				11
May 3-4, 2022																																		
Younger Lagoon				3				5																3						33				14

Discussion

Data collected indicate that Younger Lagoon Reserve (YLR) supports a wide variety of native flora and fauna, provides habitat for sensitive and threatened species, supports a very unique beach dune community, and is extensively used for research and education.

A parameter that we have mapped, and is evident from visual observation and photo documentation, is the presence of dune hummocks and downed woody material at YLR, both of which are almost entirely absent at Sand Plant Beach and Natural Bridges (Figure 9). It is likely that the hummocks and woody material are absent at Natural Bridges and Little Wilder due to human trampling, collection, and burning. These features provide habitat for plant species such as the succulent plant dudleya, which grow on downed woody material and dune hummocks at YLR, as well as burrowing owls that use burrows in hummocks and seek shelter beneath downed woody material at YLR.

Although Younger Lagoon does experience human use, the intensity and number of users is relatively small. Additionally, authorized users of the YLR beach are educated about the reserve, unique natural features, and are not allowed to collect woody material or trample dune vegetation. It is likely that increased unauthorized overnight human use of the beach prior to the pandemic had a negative impact on native mammals such as bobcats. Reserve staff will continue their public outreach and education efforts, continue to partner with UCSC campus police to ensure the security of the reserve and protect sensitive resources and ongoing research, and continue to report back to the Commission on the negative impacts of unauthorized beach use. The relatively natural state of YLR beach and dune vegetation is unique among the three sites and most pocket beaches in Santa Cruz County and likely represents a glimpse into what many of the pocket beaches in the greater Monterey Bay area looked like prior to significant human disturbance.

Open access to the beach would likely result in the loss of the unique ecological characteristics of the site and certainly reduce its effectiveness as a research area for scientific study. Controlled beach access through the free Seymour Center docent led tours, provides an appropriate level of supervised access that enables people to see and learn about the lagoon habitat while limiting impacts to the system. We recommend that this continue.

Figure 9. Younger Lagoon dune map. Survey data and resulting elevation model output shows topographic features on Younger Lagoon Beach.

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Appendix 1. Younger Lagoon Photos.


YLR Beach Photopoint #1 (W). May 9, 2022. Photographer: Eric Medina Can. Camera: Apple iPad Pro (3rd generation).


YLR Beach Photopoint #1 (NW). May 9, 2022. Photographer: Eric Medina Can. Camera: Apple iPad Pro (3rd generation).


YLR Beach Photopoint #1 (N). May 9, 2022. Photographer: Eric Medina Can. Camera: Apple iPad Pro (3rd generation).


YLR Beach Photopoint #2 (S). May 9, 2022. Photographer: Eric Medina Can. Camera: Apple iPad Pro (3rd generation).

YLR Beach Photopoint #2 (SW). May 9, 2022. Photographer: Eric Medina Can. Camera: Apple iPad Pro (3rd generation).

YLR Beach Photopoint #2 (W). May 9, 2022. Photographer: Eric Medina Can. Camera: Apple iPad Pro (3rd generation).


YLR Beach Photopoint #2 (NW). May 9, 2022. Photographer: Eric Medina Can. Camera: Apple iPad Pro (3rd generation).


YLR Beach Photopoint #3 (E). May 9, 2022. Photographer: Eric Medina Can. Camera: Apple iPad Pro (3rd generation).


YLR Beach Photopoint #3 (W). May 9, 2022. Photographer: Eric Medina Can. Camera: Apple iPad Pro (3rd generation).


YLR Beach Photopoint #3 (NW). May 9, 2022. Photographer: Eric Medina Can. Camera: Apple iPad Pro (3rd generation).


YLR Beach Photopoint #3 (N). May 9, 2022. Photographer: Eric Medina Can. Camera: Apple iPad Pro (3rd generation).


YLR Beach Photopoint #3 (NE). May 9, 2022. Photographer: Eric Medina Can. Camera: Apple iPad Pro (3rd generation).

YLR Beach Photopoint #4 (N). May 9, 2022. Photographer: Eric Medina Can. Camera: Apple iPad Pro (3rd generation).

Appendix 2. Restoration compliance monitoring report

Compliance Monitoring Report for Coastal Prairie and Wetland Restoration Sites at Younger Lagoon Reserve – Spring 2022

Brook M. Constantz

Introduction

In keeping with the goals of the restoration plans for the Younger Lagoon Reserve Terrace Lands (YLR) prepared for the California Coastal Commission (UCNRS 2010, UCNRS 2018), reserve employees, interns, and volunteers have continued to perform native plant community restoration activities. This report presents the results of the 2022 monitoring data for 2011, 2016, 2018 coastal prairie habitat plantings, and the 2016 and 2020 wetland plantings, each defined as separate restoration areas. Monitoring efforts begin two years post-planting. If an area meets restoration targets, monitoring is then conducted every other year for the first six years post-planting, and then every five years after that. If an area does not meet restoration targets, the area is monitored annually until it reaches restoration targets (UCNRS 2018).

Methods

Planting

Seeds for the coastal prairie planting projects were collected from local reference sites in coastal regions of Santa Cruz and San Mateo counties. The seeds were grown in Ray Leach stubby (SC7) conetainers™ for several weeks in the UC Santa Cruz Jean H. Langenheim Greenhouses before being planted at the site. Site preparation prior to planting typically involved the hand removal of large weeds (e.g., *Carpobrotus edulis, Raphanus sativus, Cirsium vulgare,* etc.) and tarping to reduce non-native species cover. Subsequently, a heavy layer of wood chip mulch (~10-15 cm) was applied to all restoration sites prior to planting to suppress non-native weed emergence. Teams of volunteers, interns, and staff planted the native plugs primarily between December and February using dibblers. Sites received supplemental irrigation through spot watering during the first year following planting to help improve establishment. After the first year, there was no supplemental irrigation. Follow up management included hand removal and targeted herbicide application for emerging non-native species during the first 18 – 24 months following planting. All sites were mowed twice annually in the years following planting. Fall mowing was intended to reduce thatch, and spring mowing was intended to reduce seed set from non-native species prior to native perennial development. Sites that did not reach compliance goals in the year monitored, received additional follow-up management in the subsequent year.

Sampling

To measure cover in coastal prairie and wetland habitats, a 0.25 × 1-m quadrat was placed on alternating sides of a 50-m transect tape every 5 m, for a total of ten quadrats per 50-m transect. For each transect, the quadrat was randomly placed between 1 and 5 m as the starting point. In some areas, 50-m transects did not fit the shape of the restoration area, so transects were slightly shortened or split and divided into sections to better fit the area. Cover was measured using a modified Braun-Blanquet class system within each quadrat, with increases in 5% intervals, starting with 0-5%. The midpoint of each cover class was used for data analysis (e.g. 2.5%, 7.5%, etc.). Richness was measured using a 2-m belt transect on either side of the 50-m transect tape to visually detect any native species not measured during the cover quadrat sampling. Percent shrub cover was determined from the length covered by a particular guild divided by the total length of the transect. Shrub cover may exceed 100% if multiple species are overlapping on the transect. In some areas, herbaceous cover and scrub were mixed, and both shrub measurements and herbaceous cover quadrats were quantified for these transects. Along shrub transects, herbaceous cover quadrats were only taken within non-scrub dominated areas along the transect, and thus may not be sampled every 5 m.

The 2011, 2016, and 2018 coastal prairie and 2016, 2020 wetland were measured using two to three 50 m transect, for a total of 108 quadrats combined in both areas (Figure 1, 3). Since the 2016 wetland and 2018 coastal prairie transects were shorter than 50 meters, they only had six and seven quadrats respectively. For analysis, these measurements were separated into prairie-identified and wetland-identified habitats, consistent with analyses from previous years (Lesage, 2015, 2016, 2017, 2018; Luong, 2019, 2020, 2021). For each planted area, cover was averaged across quadrats within a transect.

Prior to 2019, species richness goals were assessed from average species richness per transect at an area. However, starting in 2019, species richness goals were assessed based on total species richness at a particular restoration area. To be consistent with older monitoring reports, species richness for each planted area is a count of all unique taxa found on average per transects and at the area level for restored habitat type by year (Table 1, 2). Sites were all relatively small and around the same area (0.5 – 1.5 acres), so area-level species richness was used to assess compliance targets.

All areas are expected to meet the targets laid out for the California Coastal Commission (UCNRS 2010). The 2011 coastal prairie and the 2016 coastal prairie and wetland plantings are expected to meet six-year targets, the 2018 coastal prairie areas should meet four-year targets, and the 2020 wetland areas should meet two-year targets. Targets for all habitat types and year-post-planting are available in Appendix 1.

Results

Native species cover targets were met and surpassed in all restoration areas monitored in 2022 (Table 1). The 2016 wetland had a native cover of 25.8 ± 6.4%, which barely exceeds the ≥ 25% native cover standard and could fall below when accounting for the error margin. The 2011 and 2016 coastal prairie area had observed cover value of 44.6 ± 6.2% and 39.1 ± 6.9% respectively meeting their post-year-six target of ≥ 25%, whereas the 2011 area had a marked improvement over their previous value of 8.6 ± 2.6% native cover. The 2018 coastal prairie area had cover values of 54.1 ± 7.8% greatly surpassing the post-year-six target of ≥ 15%. Additionally, the 2020 coastal scrub area had an observed cover value of 65.9 ± 6.1% greatly surpassing its post-year-two target of ≥ 10%.

Native species richness measurements were above defined target levels for all planted areas (Table 1, 2). Transects in the 2011 and 2016 coastal prairie area had an average native species richness of 11.0 ± 0.6 and 14.5 ± 1.5 species respectively, with a total of 20 and 22 species across all transects, which meets the requirement of ≥ 8 species. The 2018 coastal prairie area had an average native species richness of 54.1 ± 7.8 species with a total of 13 native species observed across all transects which meets the requirement of ≥ 6 species. The 2016 wetland areas met their ≥ 6 species target with an average of 9.5 ± 0.5 native species per transect and 16 total native species. The 2020 wetland areas greatly exceeded their ≥ 4 species with 24 species across all transects and an average of 15.5 ± 1.5 species per transect. All planted areas showed evidence of recruitment for multiple native species.

Discussion

All restoration areas monitored in 2022 at Younger Lagoon Reserve met or exceeded the restoration targets laid out for the California Coastal Commission for their respective habitats (UCNRS 2010, UCNRS 2018). The 2011, 2016, and 2018 coastal prairie areas, and the 2016 and 2020 wetland areas all appear to successfully have restored native species cover and richness consistent with the monitoring reports from 2019 and 2020 (Luong, 2019, Luong 2020).

A comparison of monitoring data from 2020 and 2022 shows interesting trends in the wetland (Luong, 2020). In 2020, the 2016 wetland plantings had an average native cover of 41.9 ± 12.7%, but this year it reduced to an average of 25.8 ± 6.4% native cover per transect which barely exceeds the target of ≥ 25% native cover. The margin of error could cause the area to fall out of compliance in future years. Additional management, both in terms of weed control and native reintroductions could be focused on this area to prevent future non-compliance. The 2020 wetland area had a cover of 65.9 ± 6.1% which exceeds the goal of ≥ 10% native cover. Although this far exceeds the target, restored wetlands in past years often had high native cover during their first monitoring period, two-years after implementation, but then decreased native cover in subsequent years (Lesage, 2018; Luong 2020). This may indicate that YLR could consider further management action in this area. In the 2019 survey, the 2011 restored prairie had an average native cover of 25.4 ± 3.9% - which barely exceeded the target of ≥ 25% native cover, an average of 12.7 ± 0.7 native species per transect with a total of 23 unique species across all transects (Luong, 2019). This year the 2011 restored prairie native cover increased to an average of 44.6 ± 6.2% native cover per transect - which greatly exceeds the target of ≥ 25% native cover, an average 11.0 ± 0.6 species with a total of 20 unique species. The increases in native species cover indicates that supplemental planting, targeted weeding, and seasonal mowing has been successful. Though the 2018 coastal prairie had a decline in average native species from 14.5 ± 3.5 to 8.0 ± 2 species and an overall species richness decline from 20 to 13 that may be due to use of unsuitable plant species, consistent with past findings (Luong, 2020). Overall, these findings suggest that restored wetlands may be difficult to maintain without more intensive management and maintenance work that has been successful in improving other habitats that have failed to meet compliance (Table 1; 2011 coastal prairie).

Management Recommendations

In 2022, all restoration efforts at YLR met their target goals. Management strategies, such as irrigation during the first year, targeted hand-weeding, and seasonal mowing are maintaining native cover and richness in restored coastal prairie. For areas that may need greater native cover, additional planting of rhizomatous species such as *Achillea millefolium* or *Baccharis glutinosa* may aid in reaching native cover goals, especially as native cover continues to decline each year. Native grasses, such as *Elymus glaucus, Hordeum brachyantherum*, and *Stipa pulchra,* occur in nearly every area and could also be used to supplement native cover and richness. Overall, species richness values trended higher than past years (Luong, 2020).

Additional non-native species control and supplemental plantings are also recommended for the 2016 wetland area in order to prevent it from falling below compliance standards. The 2016 wetland just barely surpasses compliance standards, so if more intensive actions or adaptive management actions are not taken, this area may fall below compliance in the future as the margin of error causes the area to fall out of compliance. Previous years have all found that cover post-implementation decreased in the wetlands during the fourth year compared to the second year (Lesage, 2018; Luong, 2020). It is recommended that YLR supplement seasonal mowing in these areas with more intensive and targeted hand removal near the native species most at risk from being lost due to competition with undesirable species. Planting in these areas could also increase the likelihood they will exceed compliance standards in future years. The strong rebound of native cover in the 2011 coastal prairie habitats indicates that coastal prairie restoration is feasible with additional management.

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Tables and Figures

Figure 1. Overview map of locations for compliance monitoring in 2022 which includes the wetland, coastal scrub and prairie transects and planting areas.

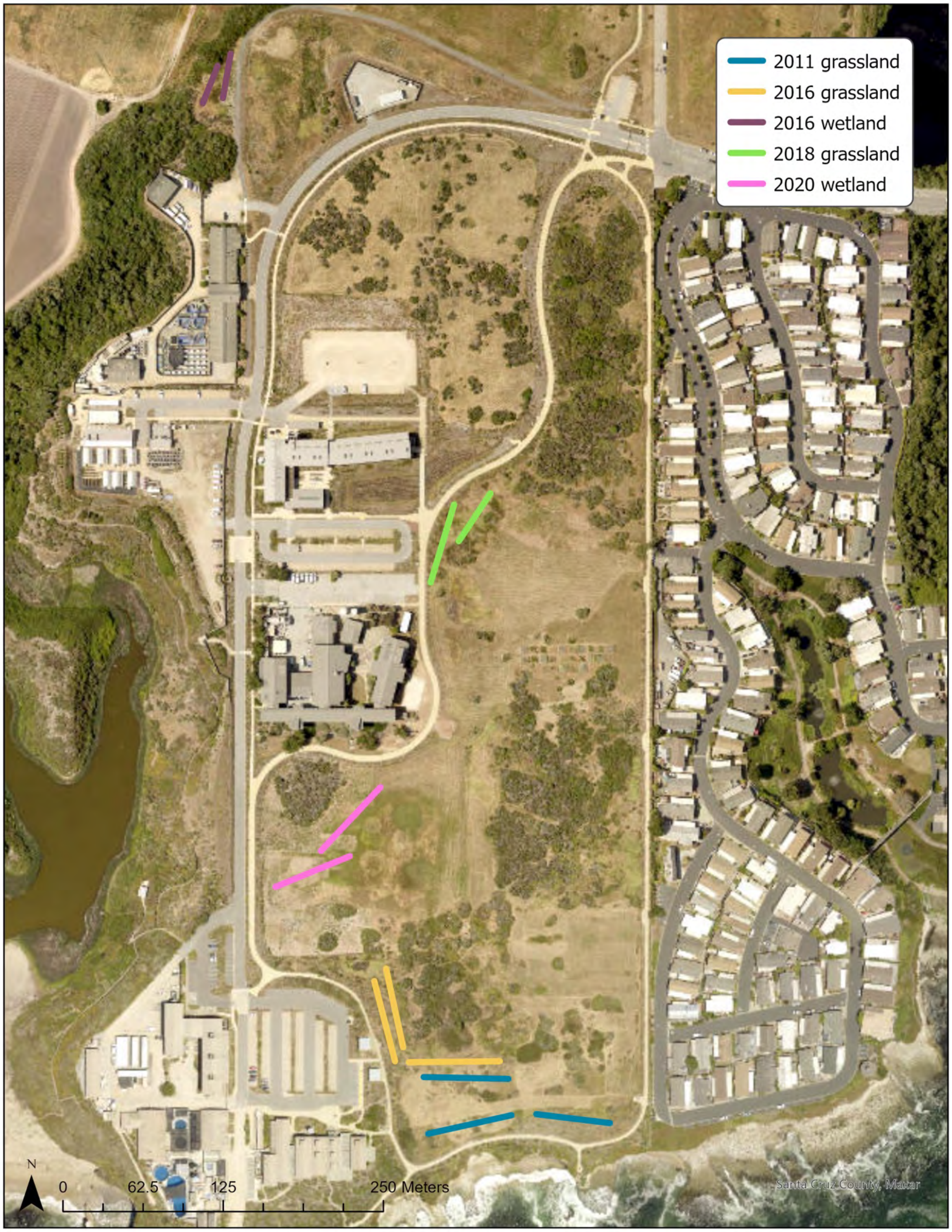

Figure 2. Map of locations for northern area in compliance monitoring in 2022.

Figure 3. Map of locations for southern area in compliance monitoring in 2022.

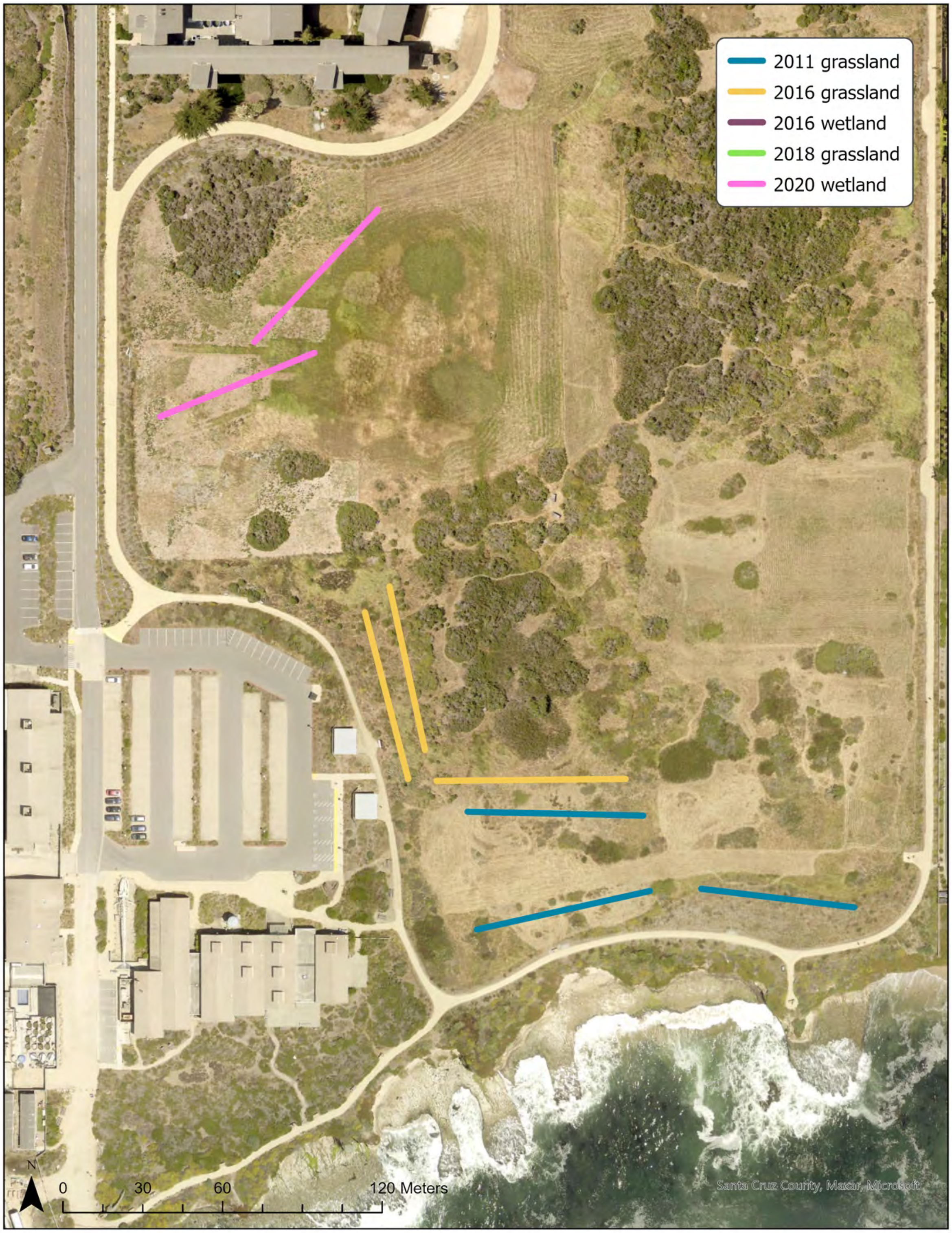

Table 1. Table of native species cover and richness targets and observed values (± SE) in the 2011, 2016 and 2018 coastal prairie and 2016 and 2020 wetland restoration areas at Younger Lagoon Reserve. Cover can exceed 100% because multiple plant canopies are accounted for.

Restoration Area	Observed Native Cover (%)	Target Native Cover (%)	Average Native Richness (species/transect)	Observed Native Richness (species/habitat)	Target Native Richness (species/habitat)
2011 Coastal Prairie	44.6 ± 6.2	≥25	11.0 ± 0.6	20	≥8
2016 Coastal Prairie	39.1 ± 6.9	≥25	14.5 ± 1.5	22	≥8
2018 Coastal Prairie	54.1 ± 7.8	≥15	8.0 ± 2	13	≥6
2016 Wetland	25.8 ± 6.4	≥25	9.5 ± 0.5	16	≥6
2020 Wetland	65.9 ± 6.1	≥10	15.5 ± 1.5	24	≥4

Table 2. Table of the native species observed in the 2011, 2016, 2018 coastal prairie and 2016 and 2020 wetland restoration areas at Younger Lagoon Reserve. Chart shows species found in at least one transect at each site. Blank cells are species that were observed in previous years. Growth forms abbreviated **(AF=Annual Forb, PF=Perennial Forb, PG=Perennial Grass, PGRM=Perennial Graminoid, AGRM = Annual Graminoid, S=Shrub, T=Tree)**. Part one contains annual forbs.

Scientific Name	Common Name	Growth Form	2011 Coastal Prairie	2016 Coastal Prairie	2018 Coastal Prairie	2016 Wetland	2020 Wetland
Clarkia davyi	Davy's clarkia	AF					X
Erigeron canadensis	Canadian horseweed	AF	X	X		X	X
Eschscholzia californica	California poppy	AF					X
Gnaphalium palustre	lowland cudweed	AF	X				
Madia sativa	coastal tarweed	AF	X	X			

Table 2*, continued*, part two has perennial forbs.

Scientific Name	Common Name	Growth Form	2011 Coastal Prairie	2016 Coastal Prairie	2018 Coastal Prairie	2016 Wetland	2020 Wetland
Achillea millefolium	yarrow	PF	X	X	X		X
Artemisia douglasiana	western mugwort	PF			X		
Baccharis glutinosa	marsh baccharis	PF	X	X		X	X
Chlorogalum pomeridianum	soap root	PF	X	X			
Grindelia stricta	gumweed	PF	X		X		
Helenium puberulum	sneezeweed	PF				X	X
Horkelia californica	California horkelia	PF		X		X	X
Potentilla anserina	silverweed	PF				X	
Ranunculus californica	California buttercup	PF	X	X			
Sidalcea malviflora	checker-bloom	PF					X
Sisyrinchium bellum	western blue-eyed grass	PF	X		X		
Symphyotrichum chilense	Pacific aster	PF	X	X	X		X
Achillea millefolium	Yarrow	PF	X	X	X		X

***Table 2**, continued*, part two has annual and perennial graminoids.

Scientific Name	**Common Name**	**Growth Form**	**2011 Coastal Prairie**	**2016 Coastal Prairie**	**2018 Coastal Prairie**	**2016 Wetland**	**2020 Wetland**
Juncus bufonius	toad rush	AGRM	X	X			
Stipa pulchra	purple needle grass	AGRM	X	X	X		X
Agrostis pallens	seashore bent grass	PGRM		X			X
Bromus carinatus	California brome	PGRM		X	X		
Carex hartfordii	Monterey sedge	PGRM			X	X	X
Cyperus eragrostis	Nutgrass	PGRM				X	X
Danthonia californica	California oatgrass	PGRM					X
Deschampsia cespitosa	tufted hair grass	PGRM	X		X		X
Distichlis spicata	salt grass	PGRM					X
Elymus glaucus	blue wild rye	PGRM	X	X			
Elymus triticoides	creeping wild rye	PGRM	X	X	X	X	X
Festuca californica	California fescue	PGRM					X
Hordeum brachyantherum	meadow barley	PGRM	X		X	X	X
Juncus effusus	soft rush	PGRM	X			X	X
Juncus mexicanus	Mexican rush	PGRM			X	X	X
Juncus patens	spreading rush	PGRM		X		X	X
Juncus xiphioides	iris-leaved rush	PGRM				X	

***Table 2**, continued*, part two has shrubs and trees.

Scientific Name	Common Name	Growth Form	2011 Coastal Prairie	2016 Coastal Prairie	2018 Coastal Prairie	2016 Wetland	2020 Wetland
Artemisia californica	California sagebrush	S		X			X
Baccharis pilularis	coyote brush	S	X	X		X	X
Diplacus aurantiacus	sticky monkey flower	S		X			
Eriophyllum staechadifolium	seaside golden yarrow	S	X	X			
Lupinus variicolor	many-colored lupine	S			X		
Rubus ursinus	Pacific blackberry	S	X	X		X	
Frangula californica	coffee berry	T		X			
Salix lasiolepis	arroyo willow	T				X	
Observed Native Species Richness:			20	22	13	16	24
Target Native Species Richness:			≥ 8	≥ 6	≥ 6	≥ 6	≥ 4

Table 3. Rainfall for Santa Cruz for rainfall years starting with the 2011-2012 rain year. Rainfall years are measured from October to September of the following year, with the most recent water year only including the cumulative precipitation to date. Data are from the Santa Cruz reporting station at California Department of Water Resources Climate Data Exchange Center (CDEC) for the Santa Cruz (CRZ) monitoring station (36.98300, -122.01700) at an elevation of 39.6 meters.

Rainfall Year	**Total Precipitation**
100 Year Average	75.8 cm
2011-2012	52.7 cm
2012-2013	45.8 cm
2013-2014	36.9 cm
2014-2015	55.1 cm
2015-2016	82.9 cm
2016-2017	129.8 cm
2017-2018	49.7 cm
2018-2019	92.6 cm
2019-2020	48.1 cm
2020-2021	37.0 cm
2021-2022	51.8 cm

Appendix 1 – Relevant Compliance Monitoring Standards for YLR Restoration Efforts

Excerpted from: *UCSC Natural Reserves Staff and the Younger Lagoon Reserve Scientific Advisory Committee (UCNRS). 2010. Enhancement and Protection of Terrace Lands at Younger Lagoon Reserve. Plan prepared for the California Coastal Commission.*

Grassland / Coastal Prairie

Performance Standard: 8 native plant species appropriate for habitat established in planted areas to comprise 25% cover.

Years Post Planting	Goal
2 years after planting	6 or more native plant species established comprising > 5% cover and evidence of natural recruitment present
4 years after planting	6 or more native plant species established comprising > 15% cover and evidence of natural recruitment present
6 years after planting and every 5 years after that	8 or more native plant species established comprising > 25% cover and evidence of natural recruitment present

Wetland

Performance Standard: 4 native plant species appropriate for habitat established in planted areas to comprise 25% cover.

Years Post Planting	Goal
2 years after planting	4 or more native plant species established comprising > 10% cover and evidence of natural recruitment present
5 years after planting and every 5 years after that	6 or more native plant species established comprising > 30% cover and evidence of natural recruitment present

Scrub

Performance Standard: 8 native plant species appropriate for habitat established in planted areas to comprise 40% cover.

Years Post Planting	Goal
2 years after planting	6 or more native plant species established comprising > 10% cover and evidence of natural recruitment present
4 years after planting	6 or more native plant species established comprising > 25% cover and evidence of natural recruitment present
6 years after planting and every 5 years after that	8 or more native plant species established comprising > 40 % cover and evidence of natural recruitment present

Appendix 3. Student reports

2022 Annual Report – Drought-Net and other Research Activities at Younger Lagoon UC Natural Reserve

Brook Constantz, Daniel Hastings, Justin Luong, Karen Holl, & Michael Loik
Environmental Studies, UC Santa Cruz

During 2022, members of the Holl and Loik labs continued the International Drought Experiment and other restoration related research. Below we summarize the status of a number of different projects.

1. Measurements and monitoring of plots in accordance with the International Drought Experiment protocol

In 2022, we measured aboveground net primary productivity (ANPP) and plant community composition of IDE drought shelter and ambient rainfall plots at YLR, as well as at the UCSC Arboretum and UCSC Campus Reserve lands at Twin Gates. There was no significant difference in biomass production between drought and ambient plots at YLR in 2022. Preliminary analyses of data from 2015-2022 show that drought shelters reduce non-native species richness and marginally decrease their cover, but do not affect native species richness or cover.

The first full-network IDE manuscript including YLR data is in review at PNAS:

Wilkins K, Smith MD, Collins SL, Knapp AK, Holdrege MC, Wilfahrt P, Ohlert T, et al. Productivity losses in grasslands are magnified if extreme drought thresholds are exceeded.

2. Decomposition & Soil Sampling at IDE

Soil sampling at the IDE plots in 2021 generated data that are now being processed for publication by colleagues as part of several multi-site analyses. These studies are led by colleagues at Colorado State University, Univ. Texas, North Carolina State Univ, and the Hawkesbury Institute for the Environment, Western Sydney University, Richmond, NSW, Australia.

3.*Baccharis pilularis* measurements and community composition

Baccharis pilularis is a relatively weedy native shrub species but can also provide ecological value. In 2018, I (Luong) observed that *B. pilularis* was only recruiting into restored (planted) and not unplanted plots, even though plots were adjacent to each other. I began measurements in 2019 and continued in 2020. Measurements include total *B. pilularis* abundance, stem diameter, overall size and leaf traits. In 2021, I resampled community composition in all IDE plots to further understand these patterns. I found restored plots supported higher B. pilularis recruitment and cover. Drought slowed but did not stop woody encroachment. This work was published in Restoration Ecology in 2022. Citation below

> Luong JC. Non-periodic grassland restoration management can promote native woody shrub encroachment. *Restoration Ecology* – https://doi.org/10.1111/rec.1 3650.

4. Glasshouse experiments on drought and competition

We (Luong and Loik) collected seeds from 5 native species used in the YLR IDE field restoration experiment and the 5 most dominant non-native species. The five native species are *Diplacus aurantiacus*, *Stipa pulchra*, *Bromus carinatus*, *Lupinus nanus* and *Sidalcea malviflora*. The non-native species consist of *Festuca bromoides*, *Carduus pycnocephalus*, *Geranium dissectum*, *Medicago polymorpha* and *Raphanus sativus*. Native species were grown in a factorial design with an episodic drought and competition treatment (where non-native species were sown) that lasted a span of 9 months. I took measurements on native and non-native above ground and below ground biomass and leaf gas exchange measurements from the native species. Leaves were also collected to be analyzed for functional traits such as specific leaf area, $\delta^{13}C$ and leaf C:N. The work is the second chapter of PhD Student, Justin Luong and is now published in Ecology and Evolution, the citation is below:

> Luong JC, Loik ME. Adjustments in physiological and morphological traits suggest drought-induced competitive release of some California plants. *Ecology and Evolution 12*(4): e8773. https://doi.org/10.1002/ECE3.8773

5. Large-scale Survey of California Grassland Restoration
From 2019-2021 we (Luong and Holl) conducted a large-scale survey of coastal CA grassland restoration projects across a 1000-km span from Santa Barbara to Humboldt. This study included 37 different restoration sites, one of which was Younger Lagoon Reserve. Overall, we found that coastal grassland restoration in California is successful at meeting project-based goals and a standard performance metric but common management practices may be resulting in biotic homogenization. Interviews with managers indicate almost all practitioners across this range select from a subset of the same seven species because they are known to grow or survive better to meet project goals. The research is currently being prepared to be submitted for publication in Ecological Applications.

6. Priority Effects in Annual Forb Establishment We (Luong and Holl) mentored undergraduate, Ernesto Chavez-Velasco in creating a priority effects field experiment in collaboration with Vaughan Williams. We investigated whether planting forbs 2 weeks earlier or native bunchgrasses 2 years earlier affects establishment and reproductive output of native forbs. We found strong that priority strongly favored forb species both in cover and seed production. Jennifer Valadez has been working with Luong to continue monitoring these plots in 2022 to assess germinant and survival counts of the targeted forb species that were used in the experiment. Jennifer Valadez will collect fruit/seed data from the plots in Summer 2022 and continue working with Holl and Luong into 2023 to continue collecting data on these plots and write a senior thesis. There are plans to write up this experiment after three years of data collection.

7. Effects of Scraping and Mounding on Annual Forb Establishment
We (Luong and Holl) mentored undergraduate, Janine Tan in designing a soil scraping and mounding experiment in collaboration with Vaughan Williams and with the assistance of Jennifer Valadez. Janine Tan will write this work as a senior thesis and Jennifer Valadez will continue to collect data on these plots in 2023. We were investigating whether shallow soil scraping and mounding affects establishment and reproductive output of native forbs. We assessed soil moisture, survival and plant community cover and Janine Tan will collect fruit/seed data in the summer of 2022. Initially we found that that mounding increases soil moisture content and overall plant cover whereas scraping decreases soil moisture and total plant cover.

Personnel
We thank YLR Staff: Elizabeth Howard, Vaughan Williams, Eric Medina, Janine Tan, and Jennifer Valadez and the numerous student workers at Younger Lagoon Reserve for making this work possible. We acknowledge support provided by the Griswold Chair (Dr. Karen Holl), the Environmental Studies Department, the California Native Grassland Association, the Institute for Social Transformation Building Belongings Program, and Sylvie Childress and the UCSC Greenhouses Staff for the various undergraduate experiments. We also thank the various interns who assisted with data collection and monitoring efforts

working for Justin Luong as part of the UCSC Grassland Ecology Research Internship and Dr. Michael Loik’s undergraduate research group during spring 2022.

Appendix 4. Photo monitoring


YLR Terrace Photopoint # 1 (S). May 9, 2022. Photographer: Eric Medina Can. Camera: Apple iPad Pro (3rd generation).


YLR Terrace Photopoint #1 (SW). May 9, 2022. Photographer: Eric Medina Can. Camera: Apple iPad Pro (3rd generation).

YLR Terrace Photopoint #1 (W). May 9, 2022. Photographer: Eric Medina Can. Camera: Apple iPad Pro (3rd generation).

YLR Terrace Photopoint # 1 (N). May 6, 2021. May 9, 2022. Photographer: Eric Medina Can. Camera: Apple iPad Pro (3rd generation).

YLR Terrace Photopoint #2 (S). May 9, 2022. Photographer: Eric Medina Can. Camera: Apple iPad Pro (3rd generation).

YLR Terrace Photopoint #2 (SW). May 9, 2022. Photographer: Eric Medina Can. Camera: Apple iPad Pro (3rd generation).

YLR Terrace Photopoint #2 (N). May 9, 2022. Photographer: Eric Medina Can. Camera: Apple iPad Pro (3rd generation).

YLR Terrace Photopoint #2 (W). May 9, 2022. Photographer: Eric Medina Can. Camera: Apple iPad Pro (3rd generation).

YLR Terrace Photopoint #3 (S). May 9, 2022. Photographer: Eric Medina Can. Camera: Apple iPad Pro (3rd generation).

YLR Terrace Photopoint #3 (SW). May 9, 2022. Photographer: Eric Medina Can. Camera: Apple iPad Pro (3rd generation).


YLR Terrace Photopoint #3 (W). May 26, 2022. Photographer: Eric Medina Can. Camera: Apple iPad Pro (3rd generation).


YLR Terrace Photopoint #3 (E). May 9, 2022. Photographer: Eric Medina Can. Camera: Apple iPad Pro (3rd generation).


YLR Terrace Photopoint #3 (N). May 9, 2022. Photographer: Eric Medina Can. Camera: Apple iPad Pro (3rd generation).


YLR Terrace Photopoint #3 (NW). May 9, 2022. Photographer: Eric Medina Can. Camera: Apple iPad Pro (3rd generation).


YLR Terrace Photopoint #3 (SE). May 9, 2022. Photographer: Eric Medina Can. Camera: Apple iPad Pro (3rd generation).


YLR Terrace Photopoint #4 (N). May 9, 2022. Photographer: Eric Medina Can. Camera: Apple iPad Pro (3rd generation).

YLR Terrace Photopoint #4 (NE). May 9, 2022. Photographer: Eric Medina Can. Camera: Apple iPad Pro (3rd generation).

YLR Terrace Photopoint #4 (E). May 9, 2022. Photographer: Eric Medina Can. Camera: Apple iPad Pro (3rd generation).


YLR Terrace Photopoint #4 (SE). May 26, 2022. Photographer: Eric Medina Can.
Camera: Apple iPad Pro (3rd generation).


YLR Terrace Photopoint #4 (SSE). May 9, 2022. Photographer: Eric Medina Can.
Camera: Apple iPad Pro (3rd generation).

YLR Terrace Photopoint #4 (S). May 9, 2022. Photographer: Eric Medina Can. Camera: Apple iPad Pro (3rd generation).

YLR Terrace Photopoint #4 (SSW). May 9, 2022. Photographer: Eric Medina Can. Camera: Apple iPad Pro (3rd generation).

YLR Terrace Photopoint #5 (E). May 9, 2022. Photographer: Eric Medina Can. Camera: Apple iPad Pro (3rd generation).

YLR Terrace Photopoint #5 (SE). May 9, 2022. Photographer: Eric Medina Can. Camera: Apple iPad Pro (3rd generation).


YLR Terrace Photopoint #5 (SSE). May 9, 2022. Photographer: Eric Medina Can. Camera: Apple iPad Pro (3rd generation).


YLR Terrace Photopoint #5 (W). May 9, 2022. Photographer: Eric Medina Can. Camera: Apple iPad Pro (3rd generation).

YLR Terrace Photopoint #6 (NW). May 9, 2022. Photographer: Eric Medina Can. Camera: Apple iPad Pro (3rd generation).

YLR Terrace Photopoint #6 (N). May 9, 2022. Photographer: Eric Medina Can. Camera: Apple iPad Pro (3rd generation).

YLR Terrace Photopoint #6 (NE). May 9, 2022. Photographer: Eric Medina Can. Camera: Apple iPad Pro (3rd generation).

YLR Terrace Photopoint #6 (E). May 9, 2022. Photographer: Eric Medina Can. Camera: Apple iPad Pro (3rd generation).


YLR Terrace Photopoint #6 (SE). May 9, 2022. Photographer: Eric Medina Can. Camera: Apple iPad Pro (3rd generation).


YLR Terrace Photopoint #6 (S). May 9, 2022. Photographer: Eric Medina Can. Camera: Apple iPad Pro (3rd generation).

YLR Terrace Photopoint #6 (SW). May 9, 2022. Photographer: Eric Medina Can.
Camera: Apple iPad Pro (3rd generation).

YLR Terrace Photopoint #6 (NW). May 26, 2022. Photographer: Eric Medina Can.
Camera: Apple iPad Pro (3rd generation).


YLR Terrace Photopoint #7 (S). May 9, 2022. Photographer: Eric Medina Can. Camera: Apple iPad Pro (3rd generation).


YLR Terrace Photopoint #7 (SW). May 9, 2022. Photographer: Eric Medina Can. Camera: Apple iPad Pro (3rd generation).


YLR Terrace Photopoint #7 (W). May 9, 2022. Photographer: Eric Medina Can. Camera: Apple iPad Pro (3rd generation).


YLR Terrace Photopoint #7 (N). May 9, 2022. Photographer: Eric Medina Can. Camera: Apple iPad Pro (3rd generation).


YLR Terrace Photopoint #8 (N). May 9, 2022. Photographer: Eric Medina Can. Camera: Apple iPad Pro (3rd generation).


YLR Terrace Photopoint #8 (NE). May 9, 2022. Photographer: Eric Medina Can. Camera: Apple iPad Pro (3rd generation).

YLR Terrace Photopoint #8 (SE). May 9, 2022. Photographer: Eric Medina Can. Camera: Apple iPad Pro (3rd generation).

YLR Terrace Photopoint #8 (S). May 9, 2022. Photographer: Eric Medina Can. Camera: Apple iPad Pro (3rd generation).

YLR Terrace Photopoint #9 (S). May 9, 2022. Photographer: Eric Medina Can. Camera: Apple iPad Pro (3rd generation).

YLR Terrace Photopoint #9 (SE). May 9, 2022. Photographer: Eric Medina Can. Camera: Apple iPad Pro (3rd generation).

YLR Terrace Photopoint #9 (E). May 9, 2022. Photographer: Eric Medina Can. Camera: Apple iPad Pro (3rd generation).

YLR Terrace Photopoint #9 (NE). May 9, 2022. Photographer: Eric Medina Can. Camera: Apple iPad Pro (3rd generation).

YLR Terrace Photopoint #9 (N). May 9, 2022. Photographer: Eric Medina Can. Camera: Apple iPad Pro (3rd generation).

YLR Terrace Photopoint #10 (W). May 9, 2022. Photographer: Eric Medina Can. Camera: Apple iPad Pro (3rd generation).

YLR Terrace Photopoint #10 (NW). May 9, 2022. Photographer: Eric Medina Can.
Camera: Apple iPad Pro (3rd generation).

YLR Terrace Photopoint #10 (N). May 9, 2022. Photographer: Eric Medina Can.
Camera: Apple iPad Pro (3rd generation).


YLR Beach Photopoint #1 (W). May 9, 2022. Photographer: Eric Medina Can. Camera: Apple iPad Pro (3rd generation).


YLR Beach Photopoint #1 (NW). May 9, 2022. Photographer: Eric Medina Can. Camera: Apple iPad Pro (3rd generation).


YLR Beach Photopoint #1 (N). May 9, 2022. Photographer: Eric Medina Can. Camera: Apple iPad Pro (3rd generation).


YLR Beach Photopoint #2 (S). May 9, 2022. Photographer: Eric Medina Can. Camera: Apple iPad Pro (3rd generation).

YLR Beach Photopoint #2 (SW). May 9, 2022. Photographer: Eric Medina Can. Camera: Apple iPad Pro (3rd generation).

YLR Beach Photopoint #2 (W). May 9, 2022. Photographer: Eric Medina Can. Camera: Apple iPad Pro (3rd generation).

YLR Beach Photopoint #2 (NW). May 9, 2022. Photographer: Eric Medina Can. Camera: Apple iPad Pro (3rd generation).

YLR Beach Photopoint #3 (E). May 9, 2022. Photographer: Eric Medina Can. Camera: Apple iPad Pro (3rd generation).


YLR Beach Photopoint #3 (W). May 9, 2022. Photographer: Eric Medina Can. Camera: Apple iPad Pro (3rd generation).


YLR Beach Photopoint #3 (NW). May 9, 2022. Photographer: Eric Medina Can. Camera: Apple iPad Pro (3rd generation).


YLR Beach Photopoint #3 (N). May 9, 2022. Photographer: Eric Medina Can. Camera: Apple iPad Pro (3rd generation).

YLR Beach Photopoint #3 (NE). May 9, 2022. Photographer: Eric Medina Can. Camera: Apple iPad Pro (3rd generation).

YLR Beach Photopoint #4 (N). May 9, 2022. Photographer: Eric Medina Can. Camera: Apple iPad Pro (3rd generation).

Appendix 5. NOID 12 (20-1) Special Conditions Implementation Reports

UC Santa Cruz NOID 12 (20-1)

SCZ-NOID-0004-20

Special Conditions Implementation Report 2

July 1, 2021 – December 31, 2021

Burrowing owl on the Younger Lagoon Reserve Beach Dunes

UC Santa Cruz NOID 12 (20-1)
Special Conditions Implementation Report 2

Overview and Executive Summary

On October 7, 2020, the California Coastal Commission approved UC Santa Cruz's NOID 12 (20-1) as consistent with UC Santa Cruz's approved Coastal Long Range Development Plan with the addition of new requirements supplementing the existing (NOID 9 18-1) five staff-recommended special conditions. The five special conditions included 1) Free Beach Tours, 2) Beach Tour Outreach Plan, 3) Beach Tour Signs, 4) Beach Tour Availability and Monitoring, and 5) Beach Access Management Plan Duration. Within 30 days of the approval (i.e., by November 7, 2020), UC Santa Cruz was required to submit a plan for implementation of special condition 2 (Outreach Plan) to the Executive Director of the California Coastal Commission. The plan for implementation of the special conditions was submitted to the Executive Director of the California Coastal Commission on November 5, 2020 and approved as submitted. Special condition 4 requires that at least every six months (i.e., by June 30th and December 31st each year), UC Santa Cruz shall submit two copies of a Beach Tour Monitoring Report for Executive Director review and approval. UC Santa Cruz's report on the implementation of these special conditions for the period of July 1, 2021 through December 31, 2021 is detailed below. UC Santa Cruz has included information from the previous four reporting periods covered under NOID 9 (18-1) and one-year prior, to provide historical and cumulative reference data. This is the second report under NOID 12 (20-1). The next report under NOID 12 (20-1) is due by June 30, 2022.

A summary of UC Santa Cruz's compliance with the five special conditions is below. Due to the COVID-19 pandemic - and in response to UC Santa Cruz's request for a COVID-19 emergency waiver, on July 10, 2020 the Commission issued a permit waiver to UC Santa Cruz's in support of COVID-19-related temporary closures and free beach tour suspensions (see UC Santa Cruz's Pub. Res. Code section 30611 notification letter to the Commission dated July 6, 2020). The Seymour Center was temporarily closed and the free beach tour program temporarily suspended in early March 2020. As requested by staff, UC Santa Cruz's notified the Commission in May 2021 of the University's phased reopening efforts. The Seymour Center partially reopened with some limited outdoor programming in summer 2021 and the Exhibit Hall reopened in October 2021; however, all of the Seymour Center's tour programs remain temporarily suspended. The University plans to restart the free beach tour program when the Seymour Center fully reopens, anticipated in spring 2022.

Special Condition	Status	Notes
1) Free Beach Tours	Completed	Upon resumption of the tours, all beach tours will continue to be offered for free without admission to the Seymour Center.
2) Beach Tour Outreach Plan	Completed & Ongoing	UC Santa Cruz's Updated Beach Tour Outreach Plan was approved by the Executive Director in November 2020 and all beach tour outreach materials now clearly state that the beach tour is free. Upon resumption of the tours, UC Santa Cruz's ongoing outreach efforts will include regular social media postings and calendar listings, including listings in Spanish and publications that serve inland communities.
3) Beach Tour Signs	Completed	UC Santa Cruz's Beach Tour Signage Plan under NOID 9 (18-1) was approved by the executive director in January 2019 and "Free Beach Tour" signs have been installed at all of the required locations.
4) Beach Tour Availability and Monitoring	Completed & Ongoing	Upon resumption of the tours, free beach tours will continue to be offered per the required schedule – a minimum of 38 times a year on weekends and weekdays, and all of the required data on tour attendees has been and will continue to be collected. UC Santa Cruz submitted all of the previously required biannual reports on the beach tours covered under NOID 9 (18-1) on-time. This is the first report under NOID 12 (20-1).
5) Beach Access Management Plan Duration	In Progress	NOID 12 (20-1) is effective through December 31, 2025. UC Santa Cruz is required to submit their next Beach Access Management Plan NOID by July 1, 2025.

Until the Seymour Center fully reopens, only historical data from previous reports are provided below for context. When tours fully resume, subsequent reports will include up-to-date data on tour participation for the reporting period.

Implementation of the NOID 9 (18-1) special conditions resulted in an approximately 18% increase in overall tour participation and more than 900% increase in walk-in/day-of tour participants in 2019 (first full year post special conditions) compared to 2018 (pre special conditions).

A summary of the free beach tour user data for 2018 (pre special conditions) and 2019 (first full year post special conditions) is below:

Year	Dates	Total Tours Offered	Total Participants	Total # of Walk-in / Day-of Participants	Total # of Participants with a Reservation
2018	January 1-December 31	38	224	5	219
2019	January 1-December 31	38	265	46	219

Although only six tours were offered before the Seymour Center was temporarily closed and the free beach tour program temporarily suspended in early March 2020 due to COVID-19, total tour attendance for the 2020 tours that were offered was more than 100% higher than tour attendance during the same time period in 2019 and more than 350% higher than tour attendance during the same time period in 2018. A summary of the free beach tour user data for the first six tours in 2018 (pre special conditions), 2019 (first full year post special conditions), and 2020 is below:

Year	Dates	Total Tours Offered	Total Participants	Total # of Walk-in / Day-of Participants	Total # of Participants with a Reservation
2018	January 1-March 7	6	17	2	15
2019	January 1-March 4	6	31	6	25
2020	January 1-March 8	6	60	5	55

In order to maintain public access and engagement during the COVID-19 pandemic, the University created a virtual bilingual beach tour that is available on the Seymour Center and Younger Lagoon Reserve websites. The virtual tour allows visitors from around the world to learn about the unique ecology and programs at the reserve in English and Spanish from the comfort of home or a mobile device.

The virtual tour websites feature a map of the reserve with marked locations where visitors can click to watch videos about the features of each type of habitat.

Virtual Tour Links:
English: https://arcg.is/11m1Ga
Spanish: https://arcg.is/0q0Czv

A UC Santa Cruz undergraduate student created the virtual tour websites and edited the videos as part of an internship project. This student completed all of the work on this project remotely, including learning about the reserve itself. A Younger Lagoon Reserve undergraduate student employee who assisted with the free in-person tours prior to the pandemic acts as the on-camera guide for both tours.

Condition 1.

FREE BEACH TOURS

All beach tours shall be offered for free, and UC Santa Cruz shall not require that beach tour users pay any separate admission fee to any other facility in order to take the beach tour. This condition shall not be construed as affecting existing, already-allowed admission fees for UC Santa Cruz's Seymour Marine Discovery Center. At a minimum, beach tour sign-ups shall be provided online (e.g., at UC Santa Cruz Marine Science Campus and Seymour Marine Discovery Center websites), by phone, and at the Seymour Marine Discovery Center front desk. UC Santa Cruz shall also identify and implement a mechanism for tracking the number of tour requests that are denied due to lack of tour availability or because tours are fully booked. All UC Santa Cruz materials referencing the beach at Younger Lagoon and/or beach tours shall be required to be modified as necessary to clearly identify that access to the beach is available for free via beach tours.

Implementation Report

Due to COVID-19 impacts, no free beach tours were offered during the last six months of 2021. Upon resumption of the tours, all beach tours will continue to be offered for free (without admission fee). Beach tour sign-ups will be available online through the Seymour Marine Discovery Center (Seymour Center) website, by phone and at the Seymour Center public admissions counter. Seymour Center staff will track any tour requests that are denied due to lack of tour availability or because tours are fully booked as part of their ongoing monitoring of all visitor programs. Seymour Center staff will record the number of participants that were denied, the number of participants that were wait listed, as well as the date of the request, the date of the tour being requested, and how participants heard about the tour (see Condition 2). All UC Santa Cruz public materials referencing the beach at Younger Lagoon and/or beach tours, including the websites below, will clearly identify that access to the beach is available for free. (Note that there is no UC Santa Cruz Marine Science Campus website; tour information will be posted to the Younger Lagoon Reserve and Seymour Marine Discovery Center websites). Notice of the temporary cessation of the free beach tours due to COVID-19 has been posted to the Younger Lagoon Reserve and the Seymour Marine Discovery Center websites.

https://youngerlagoonreserve.ucsc.edu/about-us/index.html

https://youngerlagoonreserve.ucsc.edu/research-teaching-public-service/visit/public-tours.html

https://seymourcenter.ucsc.edu/visit/behind-the-scenes-tours/

Condition 2.

BEACH TOUR OUTREACH PLAN

Within 30 days of this approval (i.e., by November 7, 2020), UC Santa Cruz shall submit two copies of an updated Outreach Plan for Executive Director review and approval, where such Plan shall identify all measures and venues to be used to advertise and increase awareness of the beach tours, including the online virtual tours. Promotional methods shall include, but are expected to not be limited to: UC Santa Cruz Marine Science Campus and Seymour Marine Discovery Center websites, press releases, calendar listings with UC Santa Cruz Events and local media (e.g., Good Times newspaper, Santa Cruz Sentinel, The Register-Pajaronian, The Half Moon Bay Review, The Monterey Herald, etc.), ads on radio (e.g., local radio stations KAZU, KRML, and others), print ads, social media (including Facebook, Twitter, and Instagram), and contacts with influential organizations in local environmental and community advocacy groups who may facilitate promotional opportunities. The Plan shall identify the language to be used in describing the virtual and free in-person beach tours (where said language shall be required to be consistent with the terms and conditions of this approval), and shall provide a schedule for each type of outreach, with the goal being to reach as many potential online viewers and potential beach tour participants as possible, including audiences beyond Santa Cruz that might not normally be reached through traditional and local means (e.g., inland communities). The Plan shall describe how UC Santa Cruz will monitor and track the Outreach Plan's execution so that UC Santa Cruz and the Coastal Commission can note the effectiveness of the plan and make changes as needed. UC Santa Cruz shall implement the updated approved Outreach Plan.

Implementation Report

Due to COVID-19 impacts, no free beach tours were offered during the second six months of 2021 and thus, no free beach tour outreach was conducted. Upon resumption of the tours, outreach will be conducted according to the following plan, which was approved by the Executive Director and includes all of the measures and venues described in Condition 2:

Venue	Language	Schedule	Mechanism for Monitoring and Tracking
Seymour Center Website	Younger Lagoon Reserve tours are free and open to the public. Space is limited to 18 participants. Call **831-459-3800** or	Permanent webpage: https://seymourcenter.ucsc.edu/visit/be	Provide link to updated website and date that updates were made

	sign-up here*. Virtual tours are available here**. * hyperlink to online sign-up **hyperlink to virtual tour	hind-the-scenes-tours/	
YLR Website	Younger Lagoon Reserve tours are free and open to the public. Space is limited to 18 participants. Call **831-459-3800** or sign-up online. Virtual tours are available online. **seymourcenter.ucsc.edu**	Permanent webpage: https://youngerlagoonreserve.ucsc.edu/research-teaching-public-service/visit/public-tours.html	Provide link to updated website and date that updates were made
Seymour Center Social Media ○ Facebook ○ Twitter ○ Instagram	Younger Lagoon Reserve tours are free and open to the public. Space is limited to 18 participants. Call **831-459-3800** or sign-up online. Virtual tours are available online. **seymourcenter.ucsc.edu**	Facebook—Monthly Twitter, Instagram ---Once a quarter	Document date that posts are made and capture a link to the post
YLR Social Media ○ Facebook ○ Instagram	Younger Lagoon Reserve tours are free and open to the public. Space is limited to 18 participants. Call **831-459-3800** or sign-up online. Virtual tours are available online. **seymourcenter.ucsc.edu**	Once a quarter	Document date that posts are made and capture a link to the post
Calendar Listings ○ UC Santa Cruz Events ○ Good Times Newspaper (Santa Cruz) ○ Register Pajaronian Newspaper (Watsonville) ○ The Half Moon Bay Review ○ The Monterey Herald ○ KAZU public radio (Santa Cruz)	Younger Lagoon Reserve tours are free and open to the public. Space is limited to 18 participants. Call **831-459-3800** or sign-up online. Virtual tours are available online. **seymourcenter.ucsc.edu** For Spanish language outlets: Las visitas guiadas a la reserva de la laguna Younger son gratuitas y están abiertas al público. El espacio está limitado a 18 participantes. Llame al **831-459-3800** o	Submitted monthly (calendar listings appear at the discretion of the media outlet.)	Document date that listings are submitted, and verify that the listing ran by capturing a link to the website (if online)

KRML (Monterey Bay)	regístrese en línea. Las visitas virtuales están disponibles en línea. **seymourcenter.ucsc.edu**		
Ads - Santa Cruz Sentinel Newspaper (Santa Cruz) - Good Times Newspaper (Santa Cruz) - KAZU public radio (Santa Cruz)	Younger Lagoon Reserve tours are free and open to the public. Space is limited to 18 participants. Call **831-459-3800** or sign-up online. Virtual tours are available online. **seymourcenter.ucsc.edu** For Spanish language outlets: Las visitas guiadas a la reserva de la laguna Younger son gratuitas y están abiertas al público. El espacio está limitado a 18 participantes. Llame al **831-459-3800** o regístrese en línea. Las visitas virtuales están disponibles en línea. **seymourcenter.ucsc.edu**	Quarterly	Document date that ads ran, and verify that the ad ran by capturing a link to the website (if online)
Press Release	Younger Lagoon Reserve tours are free and open to the public. Space is limited to 18 participants. Call **831-459-3800** or sign-up online. Virtual tours are available online. **seymourcenter.ucsc.edu** For Spanish language outlets: Las visitas guiadas a la reserva de la laguna Younger son gratuitas y están abiertas al público. El espacio está limitado a 18 participantes. Llame al **831-459-3800** o regístrese en línea. Las visitas virtuales están	Announce the virtual tours and resumption of free in-person beach tours post-COVID via two bilingual (English and Spanish) UC Santa Cruz press releases.	Document the date of the press releases, distribution list of media outlets and verify that the press releases were posted by capturing a link to the website (if online).

	disponibles en línea. **seymourcenter.ucsc.edu**		
Contacts who may facilitate promotional opportunities o SMDC Educator Email Mailing List (815 subscribers) o Homeschool Mailing Email List (124 subscribers) o Seymour Center E-newsletter list - 10,000 email recipients from all over California and beyond o UC Santa Cruz Events Email-newsletter o Andy Carman at Enviroteers, weekly newsletter o CSUMB Outdoor Recreation Resources and Opportunities Website o Outdoor World Outdoor Resources Website: https://www.theoutdoorworld.com/info/outdoor-resources	Younger Lagoon Reserve tours are free and open to the public. Space is limited to 18 participants. Call **831-459-3800** or sign-up online. Virtual tours are available online. **seymourcenter.ucsc.edu** For Spanish language outlets: Las visitas guiadas a la reserva de la laguna Younger son gratuitas y están abiertas al público. El espacio está limitado a 18 participantes. Llame al **831-459-3800** o regístrese en línea. Las visitas virtuales están disponibles en línea. **seymourcenter.ucsc.edu**	Once a quarter	Information about the tours will be emailed to contacts once a quarter. Date of email and recipients will be documented.

In addition, tour participants will be surveyed to determine how they heard about the tour. This information will be tracked with sign-up information (see Condition 1).

Condition 3.

BEACH TOUR SIGNS

UC Santa Cruz will continue to implement the Beach Tour Sign Plan that was previously-approved by the Executive Director under NOID 9 where such Plan has provided for installation of signage outside of the Seymour Marine Discovery Center and inside at its front desk, at Campus overlooks, and at other appropriate public access locations on the Marine Science Campus that describe free beach tour availability, including "day of" signs for each day beach tours are offered to ensure maximum notice is provided. All such signs shall continue to be sited and designed to be visually compatible with the area, consistent with the Campus sign program (and CLRDP sign requirements) and continue to provide clear information in a way that minimizes public view impacts. UC Santa Cruz shall continue to implement the approved Beach Tour Sign Plan from NOID 9.

Implementation Report

Due to COVID-19 impacts, no free beach tours were offered during the second six months of 2021. Upon resumption of the tours, information on the free beach tours will continue to be displayed "day of" on a large colorful monitor in the front window of the Seymour Center and at the public admissions counter. Admissions counter signage will continue to include the brown and white footprints on wave logo, and include the following language "Free Younger Lagoon Reserve Beach Tours Today" (Figures 1, 4, and 5). Signage will continue to be displayed at the information kiosk outside (Figure 3) of the Seymour Center and at Overlooks A-F (Figures 6-12).

Note, Overlook B was renamed Terrace Point Overlook, as shown on a new coastal access sign installed as a condition of Overlook B Path Repair and Replacement (SCZ-NOID-0004-19), see below.

Overlooks, admissions counter, and kiosk signage includes the brown and white footprints on wave logo, and include the following language "Free Younger Lagoon Reserve Beach Tours, Call (831) 459-3800" (Figure 2).

Figure 1. "Day of" sign design.

Figure 2. Overlooks and kiosk sign design.

Figure 3. Signage installed at Seymour Center information kiosk (photo taken pre-pandemic).

Figure 4. Signage installed at Seymour Center front window (photo taken pre-pandemic).

Figure 5. Signage installed at the Seymour Center admissions desk (photo taken pre-pandemic).

Figure 6. Signage installed at Overlook A.

Figure 7. Signage installed at Overlook A (close-up).

Figure 8. Signage installed at Overlook B (Terrace Point).

Figure 9. Signage installed at Overlook C.

Figure 10. Signage installed at Overlook D.

Figure 11. Signage installed at Overlook E.

Figure 12. Signage installed at Overlook F.

Condition 4.

BEACH TOUR AVAILABILITY AND MONITORING

UC Santa Cruz shall offer at least four beach tours per month (of which at least one per month is a weekday tour and at least two per month are weekend tours) from March 1st through September 30th each year and shall provide at least two beach tours per month (of which at least one per month is a weekday tour and at least one per month is a weekend tour) otherwise (totaling a minimum of 38 total beach tours per year). UC Santa Cruz may limit the number of beach tour participants to 18 persons per tour, but this number may be exceeded per tour on a case-by-case basis, and beach tours shall not require any minimum number of participants to be provided (i.e., if at least one person signs up, the tour shall be provided). UC Santa Cruz shall document the date/time and number of participants for each beach tour, as well as the number of tour requests that are denied due to lack of tour availability or because tours are fully booked (see also Condition 1).

At least every six months (i.e., by June 30 and December 31 of each year), UC Santa Cruz shall submit two copies of a Beach Tour Monitoring Report for Executive Director review and approval, where the Report shall, at a minimum, provide information regarding compliance with these conditions of approval, including a section identifying UC Santa Cruz's activities under the approved updated Beach Tour Outreach Plan (see Condition 2) and which shall include specific information regarding the dates that each advertisement for beach tours was placed in each venue/media/social media outlet, as well as the required information described in the previous paragraph. Each such Monitoring Report shall include a section that identifies recommendations about whether user data suggests that beach tours should be increased in terms of frequency of tours and/or number of tour attendees, or otherwise modified to better respond to user demand, including the potential to offer a more limited beach area tour (e.g., designed to allow participants to access just the sandy beach area itself in a shorter amount of time) as a means of offsetting demand. Each Monitoring Report shall also include a section that describes how the beach-lagoon ecosystem has responded to beach tours. This assessment will include data and analysis useful for assessing whether the ecosystem shows any impacts from beach tours. This assessment will be used to help determine if larger tours have any impacts on the YLR ecosystem, its environmental quality, and UC Santa Cruz research opportunities at the site. UC Santa Cruz shall implement any Executive Director-approved recommendations from each Beach Tour Monitoring Report.

Implementation Report

Due to COVID-19 impacts, no free beach tours were offered during the second six months of 2021 and no data were collected. Upon resumption of the tours, free beach tours will be offered at least four times per month (at least one on a weekday and two on a weekend tours) from March 1st through September 30th each year, and will be offered at least two times per month (at least one on a weekday and one on a weekend) for the remainder of the year (a minimum of 38 total beach tours per year). Beach tour participants will be limited to 18 persons per tour, but this number may be exceeded per tour on a case by case basis, and beach tours will not require any minimum number of participants to be provided (i.e., if at least one person signs up, the tour will be provided). UC Santa Cruz will document the date/time and number of participants for each beach tour, as well as the number of tour requests that are denied due to lack of tour availability or because tours are fully booked (see also Condition 1). In addition, tour participants will be surveyed to determine how they heard about the tour. This information will be tracked with sign-up information (see Conditions 1 and 2).

At least every six months (i.e., by June 30th and December 31st each year), UC Santa Cruz will submit two copies of a Beach Tour Monitoring Report for Executive Director review and approval, where the Report will at a minimum provide information regarding compliance with these conditions of approval, including a section identifying UC Santa Cruz's activities under the approved updated Beach Tour Outreach Plan (see Condition 2), as well as the required information described in the previous paragraph and Condition 4 above. This is the second such report under this implementation plan and has been submitted by December 31, 2021.

Due to COVID-19 impacts, a total of six free beach tours were offered in 2020 (See Appendix 1). In 2020, beach tour participants were limited to 14 persons per tour (previous NOID 9 (18-1) limit of 14 was increased to 18 under NOID 12) on all but one tour. On January 2, 2020, at the discretion of the tour docent, the number of beach tour participants was increased to 15 persons to accommodate all persons who desired to take the beach tour that day.

UC Santa Cruz offered 38 beach tours (265 participants) during 2019 (Appendix 1). All but one of these tours had at least one participant. Only one tour did not go out due to lack of sign-ups. Sixteen of the tours that went out included walk-in / "day-of" participants. Two tours were overbooked in 2019.

In comparison, UC Santa Cruz offered 38 beach tours (224 participants) during 2018 (Appendix 2). Six tours did not go out due to lack of sign-ups, and one tour was canceled due to weather. Four of the tours that went out included walk-in / "day-of" participants. No tours were overbooked during 2018.

Although not required by the special conditions, in addition to tracking user data, UC Santa Cruz also collected data on the biological impacts of the tours. Beginning on April 14, 2019, Younger Lagoon Reserve staff accompanied tours, and documented impacts to avian wildlife on the beach. Staff observed birds flushing from the wet sandy beach, beach dunes, coastal stack, and lagoon in response to all but three of the tours they attended (see Appendix 3). The average number of avian species present post-tour was significantly less than the average number of avian species pre-tour (p=.0004, paired t-test; See Figure 13).

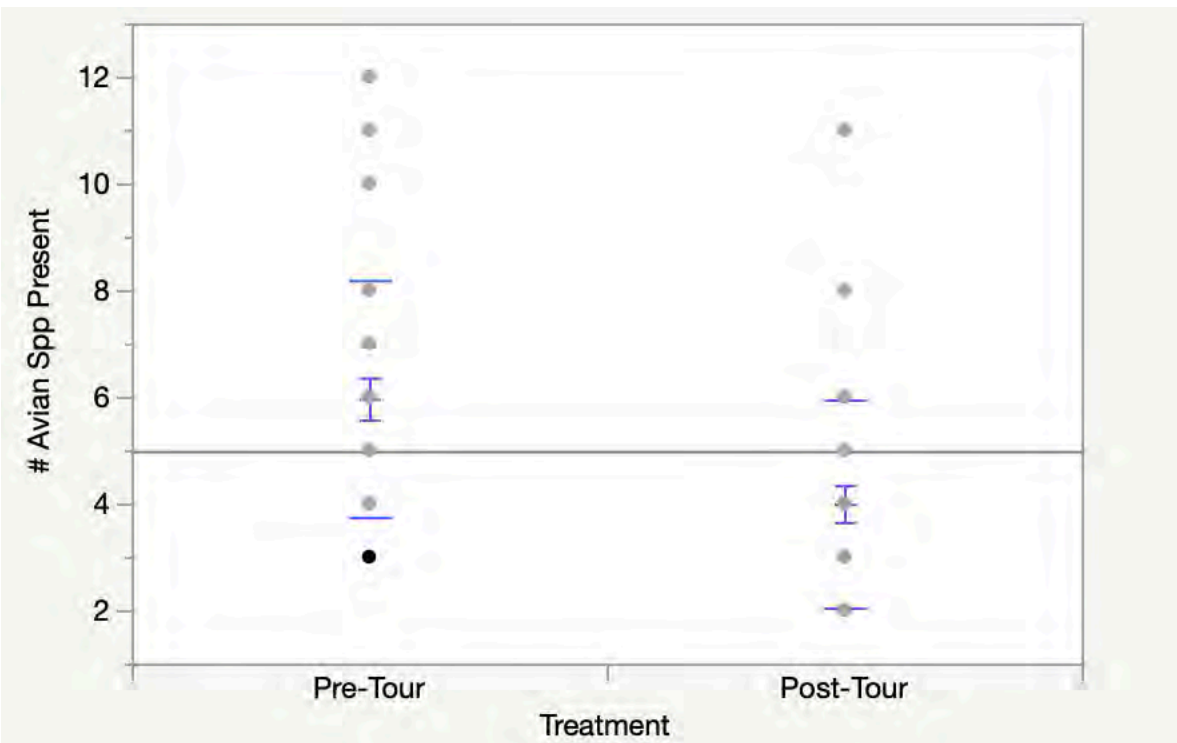

Figure 13. Effect of tours on avian species. Blue I-bars indicate mean, standard error, and standard deviation. The average number of avian species present pre-tour was 5.97 +/- 2.22 (+/- sd). The average number of avian species present post-tour was 4.00 +/- 1.95 (+/- sd). The average number of avian species present post-tour was significantly less than the average number of avian species pre-tour (p=.0004, paired t-test).

Recommendations

Although only in place for 30 months and currently paused due to COVID-19 impacts, the beach tours as specified by UC Santa Cruz's NOIDs 9 (18-1) and 12 (20-1) special conditions appear to be meeting user demand. Total tour attendance for the 2020 tours that were offered was more than 100% higher than tour attendance during the same time period in 2019 (first full year post special conditions) and more than 350% higher than tour attendance during the same time period in 2018 (pre special conditions). During the 24 months covered by NOID 9 (18-1), eight participants were denied a tour due to overdemand. NOID 12 (20-1) continues the five NOID 9 special conditions, increases the upper limit of tour attendees and requires additional outreach efforts.

The documented negative biological impacts to avian wildlife described above, along with ongoing quarterly beach monitoring efforts indicate that open access to the beach would result in the loss of the unique ecological characteristics of the site, reduce its effectiveness as a research area for scientific study, and likely have a negative impact on sensitive and protected species (See 2009-2010, 2010-2011, 2011-2012, 2012-2013, 2013-2014, 2014-2015, 2015-2016, 2016-2017, 2017-2018, 2018-2019, 2019-2020, and 2020-2021 Annual Reports).

We recommend that the balance between resource protection of the beach and lagoon area – all of which are considered Environmentally Sensitive Habitat Area (ESHA) or ESHA buffer by the Commission, and public access continue to be carefully evaluated and managed. Although similar in many ways to other local pocket beaches, Younger Lagoon beach supports a unique assemblage of flora and fauna, including rare and endangered species. As part of the UC Natural Reserve System, Younger Lagoon Reserve acts as a protected living laboratory and outdoor classroom for teaching and research and is managed in trust for the people of the State of California by the University.

Condition 5.

BEACH ACCESS MANAGEMENT PLAN DURATION

This approval for UC Santa Cruz's public beach access management plan at Younger Lagoon Beach shall be effective through December 31, 2025. UC Santa Cruz shall submit a complete NOID, consistent with all CLRDP requirements, to implement its next public beach access management plan at Younger Lagoon Beach (for the period from January 1, 2026 to December 31, 2030) no later than July 1, 2025. Such a complete NOID shall, at a minimum, summarize the results of the Beach Tour Monitoring Reports (see Condition 4), and shall identify the manner in which UC Santa Cruz's proposed management plan responds to such data, including with respect to opportunities to increase public access to the beach area when considered in light of potential impacts to UC Santa Cruz research and coastal resources. If such a complete NOID has not been submitted by July 1, 2025, then UC Santa Cruz shall allow supervised (via beach and trail monitors only) general public access to Younger Lagoon Beach during daylight hours (i.e., one hour-before sunrise to one-hour after sunset) until such NOID has been submitted.

Implementation Report

UC Santa Cruz will submit a complete NOID, consistent with all CLRDP requirements, to implement its next public beach access management plan at Younger Lagoon Beach (for the period from January 1, 2026 to December 31, 2030) no later than July 1, 2025.

Appendix 1. Tour Data July 1, 2021 – December 31, 2021

Tour Date	Day	Participants	Walk in	Reservation	No Show	Denial / Wait list
7/1/21*	Thursday	-	-	-	-	-
7/11/21*	Sunday	-	-	-	-	-
7/15/21*	Thursday	-	-	-	-	-
7/25/21*	Sunday	-	-	-	-	-
8/5/21*	Thursday	-	-	-	-	-
8/8/21*	Sunday	-	-	-	-	-
8/19/21*	Thursday	-	-	-	-	-
8/22/21*	Sunday	-	-	-	-	-
9/2/21*	Thursday	-	-	-	-	-
9/12/21*	Sunday	-	-	-	-	-
9/16/21*	Thursday	-	-	-	-	-
9/26/21*	Sunday	-	-	-	-	-
10/7/21*	Thursday	-	-	-	-	-
10/10/21*	Sunday	-	-	-	-	-
11/4/21*	Thursday	-	-	-	-	-
11/14/21*	Sunday	-	-	-	-	-
12/2/21*	Thursday	-	-	-	-	-
12/5/21*	Sunday	-	-	-	-	-

*7/1/21 - 12/5/21 – Canceled due to COVID-19 impacts.

Appendix 1 (cont). Tour Data January 1, 2021 – June 30, 2021

Tour Date	Day	Participants	Walk in	Reservation	No Show	Denial / Wait list
1/7/21*	Thursday	-	-	-	-	-
1/10/21*	Sunday	-	-	-	-	-
2/4/21*	Thursday	-	-	-	-	-
2/14/21*	Sunday	-	-	-	-	-
3/4/21*	Thursday	-	-	-	-	-
3/14/21*	Sunday	-	-	-	-	-
3/18/21*	Thursday	-	-	-	-	-
3/28/21*	Sunday	-	-	-	-	-
4/1/21*	Thursday	-	-	-	-	-
4/11/21*	Sunday	-	-	-	-	-
4/15/21*	Thursday	-	-	-	-	-
4/25/21*	Sunday	-	-	-	-	-
5/6/21*	Thursday	-	-	-	-	-
5/9/21*	Sunday	-	-	-	-	-
5/20/21*	Thursday	-	-	-	-	-
5/23/21*	Sunday	-	-	-	-	-
6/3/21*	Thursday	-	-	-	-	-
6/13/21*	Sunday	-	-	-	-	-
6/17/21*	Thursday	-	-	-	-	-
6/27/21*	Sunday	-	-	-	-	-
2021 TOTAL	-	-	-	-	-	-

*1/7/21 - 6/27/21 – Canceled due to COVID-19 impacts.

Appendix 1 (cont). Tour Data July 1, 2020 – December 31, 2020

Tour Date	Day	Participants	Walk in	Reservation	No Show	Denial / Wait list
7/2/20*	Thursday	-	-	-	-	-
7/12/20*	Sunday	-	-	-	-	-
7/16/20*	Thursday	-	-	-	-	-
7/26/20*	Sunday	-	-	-	-	-
8/6/20*	Thursday	-	-	-	-	-
8/9/20*	Sunday	-	-	-	-	-
8/20/20*	Thursday	-	-	-	-	-
8/23/20*	Sunday	-	-	-	-	-
9/3/20*	Thursday	-	-	-	-	-
9/13/20*	Sunday	-	-	-	-	-
9/17/20*	Thursday	-	-	-	-	-
9/27/20*	Sunday	-	-	-	-	-
10/1/20*	Thursday	-	-	-	-	-
10/11/20*	Sunday	-	-	-	-	-
11/5/20*	Thursday	-	-	-	-	-
11/8/20*	Sunday	-	-	-	-	-
12/3/20*	Thursday	-	-	-	-	-
12/6/20*	Sunday	-	-	-	-	-

*7/2/20 - 12/6/20 – Canceled due to COVID-19 impacts.

Appendix 1 (cont). Tour Data January 1, 2020 – June 30, 2020

Tour Date	Day	Participants	Walk in	Reservation	No Show	Denial / Wait list
1/2/20	Thursday	15	4	20	9	0
1/12/20	Sunday	13	1	18	6	0
2/6/20	Thursday	9	0	18	9	0
2/9/20	Sunday	4	0	5	1	0
3/5/20	Thursday	8	0	8	0	0
3/8/20	Sunday	11	0	14	3	0
3/19/20*	Thursday	-	-	-	-	-
3/22/20*	Sunday	-	-	-	-	-
4/2/20*	Thursday	-	-	-	-	-
4/5/20*	Sunday	-	-	-	-	-
4/16/20*	Thursday	-	-	-	-	-
4/26/20*	Sunday	-	-	-	-	-
5/7/20*	Thursday	-	-	-	-	-
5/10/20*	Sunday	-	-	-	-	-
5/21/20*	Thursday	-	-	-	-	-
5/24/20*	Sunday	-	-	-	-	-
6/4/20*	Thursday	-	-	-	-	-
6/14/20*	Sunday	-	-	-	-	-
6/18/20*	Thursday	-	-	-	-	-
6/28/20*	Sunday	-	-	-	-	-
2020 TOTAL	**-**	**60**	**5**	**83**	**28**	**0**

*3/19/20 - 6/28/20 – Canceled due to COVID-19 impacts.

Appendix 1 (cont.). Tour Data January 1, 2019 – June 30, 2019

Tour Date	Day	Participants	Walk in	Reservation	No Show	Denial / Wait list
1/3/19	Thursday	2	2	0	0	0
1/13/19	Sunday	7	0	7	0	0
2/7/19	Thursday	3	0	3	0	0
2/10/19	Sunday	6	1	5	0	0
3/3/19	Sunday	10	3	7	0	0
3/719	Thursday	3	0	4	1	0
3/1019	Sunday	9	6	3	0	0
3/2119	Thursday	3	0	4	1	0
4/4/19	Thursday	10	6	4	0	0
4/7/19	Sunday	9	4	5	0	0
4/14/19	Sunday	9	2	11	4	0
4/18/19	Thursday	5	1	5	1	0
5/2/19	Thursday	1	0	1	0	0
5/5/19*	Sunday	0	0	0	0	0
5/12/19	Sunday	2	0	2	0	0
5/16/19	Thursday	1	0	1	0	0
6/2/19	Sunday	3	0	3	0	0
6/6/19	Thursday	1	1	0	0	0
6/9/19**	Sunday	16	4	14	0	2
6/20/19	Thursday	3	1	2	0	0

*5/5/19 - No tour; no participants.

**6/9/19 - Denial due to overdemand; participants accommodated on a Seymour Center daily tour, which included vistas of the lagoon and beach, later that day.

Appendix 1 (cont.). Tour Data July 1, 2019 – December 31, 2019

Tour Date	Day	Participants	Walk in	Reservation	No Show	Denial / Wait list
7/7/19	Sunday	14	4	13	3	0
7/11/19	Thursday	14	2	12	0	0
7/14/19	Thursday	17	5	18	6	0
7/18/19	Thursday	12	2	13	3	0
8/1/19	Thursday	10	0	18	8	0
8/4/19*	Sunday	14	0	21	1	6
8/11/19	Sunday	10	0	10	0	0
8/15/19	Thursday	5	0	5	0	0
9/1/19	Sunday	13	0	14	1	0
9/5/19	Thursday	6	0	6	0	0
9/8/19	Sunday	4	0	4	0	0
9/19/19	Thursday	2	0	2	0	0
10/3/19	Thursday	7	2	5	0	0
10/13/19	Sunday	9	0	9	0	0
11/7/19	Thursday	6	0	6	0	0
11/10/19	Sunday	8	0	13	5	0
12/1/19	Sunday	2	0	11	9	0
12/9/19	Thursday	9	0	9	0	0
2019 TOTAL	**-**	**265**	**46**	**270**	**43**	**8**
GRAND TOTAL	**-**	**325**	**51**	**353**	**71**	**8**

*8/4/19 - Denial due to overdemand. Participants offered a Seymour Center daily tour, which includes vistas of the lagoon and beach.

Appendix 2. Tour Data January 1, 2018 – June 30, 2018 (pre special conditions)

Tour Date	Day	Participants	Walk in	Reservation	No Show
1/4/18	Thursday	3	1	2	0
1/14/18	Sunday	3	0	3	0
2/1/18	Thursday	6	0	6	0
2/11/18	Sunday	2	1	1	0
3/1/18*	Thursday	1	0	1	0
3/4/18	Sunday	2	0	2	0
3/11/18	Sunday	6	1	5	0
3/15/18	Thursday	2	2	0	0
4/5/18	Thursday	11	0	11	0
4/8/18	Sunday	2	0	2	0
4/19/18	Thursday	8	0	8	0
4/22/18	Sunday	2	0	3	1
5/3/18	Thursday	11	0	11	0
5/6/18	Sunday	7	0	7	0
5/13/18	Sunday	2	0	2	0
5/17/18**	Thursday	0	0	0	0
6/3/18	Sunday	0	0	0	0
6/7/18	Thursday	10	0	11	1
6/10/18	Sunday	7	0	7	0
6/21/18	Thursday	10	0	13	3

*3/1/18 – Canceled due to weather.
**5/17/18 – Canceled; no sign-ups.
***6/3/18 – Canceled; no sign-ups.

Appendix 2 (cont.). Tour Data July 1, 2018 – December 31, 2018 (pre special conditions)

Tour Date	Day	Participants	Walk in	Reservation	No Show
7/1/18	Sunday	9	0	11	2
7/5/18	Thursday	13	0	13	0
7/8/18	Sunday	9	0	10	1
7/19/18*	Sunday	0	0	0	0
8/2/18**	Thursday	0	0	0	0
8/5/18	Sunday	13	0	15	2
8/12/18	Sunday	2	0	2	0
8/16/18	Thursday	9	0	9	0
9/2/18	Sunday	18	0	18	0
9/6/18	Thursday	6	0	6	0
9/9/18	Sunday	5	0	5	0
9/27/28	Thursday	14	0	15	1
10/4/18	Thursday	10	0	12	2
10/14/18	Sunday	8	0	8	0
11/1/18***	Thursday	0	0	0	0
11/11/18	Sunday	7	0	7	0
12/2/18	Sunday	6	0	8	2
12/6/18****	Thursday	0	0	0	0
2018 TOTAL	**-**	**224**	**5**	**234**	**15**

*7/19/18 – Canceled; no sign-ups.
**8/2/18 – Canceled; no sign-ups.
***11/1/18– Canceled; no sign-ups.
****12/6/18– Canceled; no sign-ups.

Appendix 3. Avian Wildlife Impact Data, July 1, 2021 – December 31, 2021

Tour Date	Day	Species Present	Species Flushed
7/1/21*	Thursday	-	-
7/11/21*	Sunday	-	-
7/15/21*	Thursday	-	-
7/25/21*	Sunday	-	-
8/5/21*	Thursday	-	-
8/8/21*	Sunday	-	-
8/19/21*	Thursday	-	-
8/22/21*	Sunday	-	-
9/2/21*	Thursday	-	-
9/12/21*	Sunday	-	-
9/16/21*	Thursday	-	-
9/26/21*	Sunday	-	-
10/7/21*	Thursday	-	-
10/10/21*	Sunday	-	-
11/4/21*	Thursday	-	-
11/14/21*	Sunday	-	-
12/2/21*	Thursday	-	-
12/5/21*	Sunday	-	-
2021 TOTAL	-	-	-

*7/1/21 – 12/5/21 – Canceled due to COVID-19 impacts. No biological data collected.

Appendix 3 (cont). Avian Wildlife Impact Data, January 1, 2021 – June 30, 2021

Tour Date	Day	Species Present	Species Flushed
1/7/21*	Thursday	-	-
1/10/21*	Sunday	-	-
2/4/21*	Thursday	-	-
2/14/21*	Sunday	-	-
3/4/21*	Thursday	-	-
3/14/21*	Sunday	-	-
3/18/21*	Thursday	-	-
3/28/21*	Sunday	-	-
4/1/21*	Thursday	-	-
4/11/21*	Sunday	-	-
4/15/21*	Thursday	-	-
4/25/21*	Sunday	-	-
5/6/21*	Thursday	-	-
5/9/21*	Sunday	-	-
5/20/21*	Thursday	-	-
5/23/21*	Sunday	-	-
6/3/21*	Thursday	-	-
6/13/21*	Sunday	-	-
6/17/21*	Thursday	-	-
6/27/21*	Sunday	-	-

*1/4/21 - 6/27/21 – Canceled due to COVID-19 impacts. No biological data collected.

Appendix 3 (cont). Avian Wildlife Impact Data, July 1, 2020 – December 31, 2020

Tour Date	Day	Species Present	Species Flushed
7/2/20*	Thursday	-	-
7/12/20*	Sunday	-	-
7/16/20*	Thursday	-	-
7/26/20*	Sunday	-	-
8/6/20*	Thursday	-	-
8/9/20*	Sunday	-	-
8/20/20*	Thursday	-	-
8/23/20*	Sunday	-	-
9/3/20*	Thursday	-	-
9/13/20*	Sunday	-	-
9/17/20*	Thursday	-	-
9/27/20*	Sunday	-	-
10/1/20*	Thursday	-	-
10/11/20*	Sunday	-	-
11/5/20*	Thursday	-	-
11/8/20*	Sunday	-	-
12/3/20*	Thursday	-	-
12/6/20*	Sunday	-	-
2020 TOTAL	**-**	**-**	**-**

*7/2/20 - 12/6/20 – Canceled due to COVID-19 impacts. No biological data collected.

Appendix 3 (cont). Avian Wildlife Impact Data, January 1, 2020 – June 30, 2020

Tour Date	Day	Species Present	Species Flushed
1/2/20	Thursday	AMCO, AUWA, BLPH, BRCO, GCSP, MALL, NOHA, PIGU, SAPH, WEGU	BLPH, AUWA
1/12/20*	Sunday	AMCO, BLPH, BRCO, CAGO, COHA, GREG, MALL, PECO, SAPH, SNEG, WEGU	-
2/6/20	Thursday	BRCO, SNEG, WEGU	SNEG
2/9/20*	Sunday	BRCO, GREG, WEGU	-
3/5/20	Thursday	CAGO, GREG, MALL, PECO	MALL
3/8/20	Sunday	AMCO, BRCO, CAGO, CITE, MALL, SNEG, WHIM	BRCO, CITE, MALL, SNEG
3/19/20**	Thursday	-	-
3/22/20**	Sunday	-	-
4/2/20**	Thursday	-	-
4/5/20**	Sunday	-	-
4/16/20**	Thursday	-	-
4/26/20**	Sunday	-	-
5/7/20**	Thursday	-	-
5/10/20**	Sunday	-	-
5/21/20**	Thursday	-	-
5/24/20**	Sunday	-	-
6/4/20**	Thursday	-	-
6/14/20**	Sunday	-	-

* 1/12/20 and 2/9/20 - No birds flushed.

**3/19/20 - 6/28/20 – Tours canceled due to COVID-19 impacts. No biological data collected.

AMCO – American coot, **AMCR** – American crow, **AMRO** – American robin, **AMWI** – American whimbrel, **BARS** – Barn swallow, **BHCO** – Brown-headed cowbird, **BLOY** – Black oystercatcher, **BLPH** – Black phoebe, **BRAC** – Brand's cormorant, **BRAN** – Brant, **BRBL** – Brewer's blackbird, **BRPE** – Brown pelican, **CAGU** – California Gull, **CCGO** – Canada goose, **CLSW** – Cliff swallow, **CORA** – Common raven, **GBHE** – Great blue heron, **GREG** – Great egret, **GRHE** – Green heron, **KILL** – Killdeer, **MALL** – Mallard, **NOHA** – Northern harrier, **NOMO** – Northern mockingbird, **PECO** – Pelagic cormorant, **PIGU** – Pigeon guillemot, **RNPH** – Red-necked phalarope, **RSHA** – Red-shouldered hawk, **RWBL** – Red-winged blackbird, **SAND** – Sanderling, **SAPH** – Say's phoebe, **SNEG** – Snowy Egret, **SOSP** – Song sparrow, **TUVU** – Turkey vulture, **WEGU** – Western gull, **WESA** – Western sandpiper

Appendix 3 (cont.). Avian Wildlife Impact Data, April 14, 2019 – June 30, 2019

Tour Date	Day	Species Present	Species Flushed
4/14/19	Sunday	AMCO, BLOY, BRAC, CCGO, GREG, MALL, SNEG, WEGU	BLOY, CCGO, MALL
4/18/19	Thursday	BLOY, BRAC, MALL, SNEG, SOSP, WEGU	BLOY, MALL, SNEG
5/2/19	Thursday	CCGO, BRBL, GREG, KILL, MALL, RSHA, WEGU	BRBL, CAGO, GREG, MALL, WEGU
5/5/19*	Sunday	No tour	No tour
5/12/19	Sunday	MALL, NOMO RNPH, WEGU, WESA	WESA
5/16/19	Thursday	BLPH, BRAC, GREG, KILL, MALL, RNPH, WEGU	MALL
6/2/19	Sunday	BARS, BLPH, MALL, PIGU, WEGU, WESA	BLPH, MALL WESA
6/6/19	Thursday	AMRO, BARS, BLPH, BRAC, BRBL, CAGO, CLSW, GREG, MALL, PECO, PIGU, WEGU	CAGO, GREG, PIGU, WEGU
6/9/19	Sunday	BARS, BLPH, BRAC, KILL, PIGU, RWBL, SOSP, WEGU	BARS, BLPH, PIGU, RWBB
6/20/19	Thursday	AMCR, BARS, BLPH, BRAC, PIGU, WEGU	BLPH, PIGU, WEGU

*5/5/19 - No tour; no participants

AMCO – American coot, **AMCR** – American crow, **AMRO** – American robin, **AMWI** – American whimbrel, **BARS** – Barn swallow, **BHCO** – Brown-headed cowbird, **BLOY** – Black oystercatcher, **BLPH** – Black phoebe, **BRAC** – Brand's cormorant, **BRAN** – Brant, **BRBL** – Brewer's blackbird, **BRPE** – Brown pelican, **CAGU** – California Gull, **CCGO** – Canada goose, **CLSW** – Cliff swallow, **CORA** – Common raven, **GBHE** – Great blue heron, **GREG** – Great egret, **GRHE** – Green heron, **KILL** – Killdeer, **MALL** – Mallard, **NOHA** – Northern harrier, **NOMO** – Northern mockingbird, **PECO** – Pelagic cormorant, **PIGU** – Pigeon guillemot, **RNPH** – Red-necked phalarope, **RSHA** – Red-shouldered hawk, **RWBL** – Red-winged blackbird, **SAND** – Sanderling, **SAPH** – Say's phoebe, **SNEG** – Snowy Egret, **SOSP** – Song sparrow, **TUVU** – Turkey vulture, **WEGU** – Western gull, **WESA** – Western sandpiper

Appendix 3 (cont.). Avian Wildlife Impact Data, July 1, 2019 – December 31, 2019

Tour Date	Day	Species Present	Species Flushed
7/7/19	Sunday	BARS, BHCO, BRPE, GREG, WEGU	GREG, WEGU
7/11/19	Thursday	CAGU, CORA, NOHA, PECO, PIGU, WEGU	PECO
7/14/19	Thursday	AMCR, CAGU, PECO, WEGU	WEGU
7/18/19	Thursday	AMCO, BARS, CLSW, WEGU	WEGU
8/1/19	Thursday	CORA, MALL, PECO, RNPH, SNEG	MALL, RNPH
8/4/19	Sunday	GBHE, PIGU, SNEG, WEGU	GBHE, SNEG
8/11/19	Sunday	GBHE, GREG, PECO, RNPH, SNEG, WESA	GREG, WESA
8/15/19	Thursday	BARS, GBHE, GREG, PECO, WESA	GBHE, GREG
9/1/19	Sunday	CAGU, PECO, SNEG	SNEG
9/5/19	Thursday	BLPH, GREG, PECO, SNEG, WEGU	GREG, SNEG
9/8/19	Sunday	NOHA, PECO, SAND, WEGU, WHIM	NOHA
9/19/19	Thursday	GREG, GRHE, PECO, RNPH, RTHA, SAND, WEGU	GRHE, PECO, RTHA
10/3/19	Thursday	BLPH, BRPE, CAGU, KILL, PECO, SAPH, SNEG, WHIM	BLPH, CAGU, SAPH, SNEG
10/13/19	Sunday	BLPH, NOHA, PECO, SOSH, WEGU	NOHA
11/7/19	Thursday	AMWI, BLPH, BRAN, PECO, RTHA, SAPH, WEGU	BLPH, RTHA
11/10/19*	Sunday	CLSW, PECO, TUVU	-
12/1/19**	Sunday	-	-
12/9/19	Thursday	AMWI, BLPH, BRPE, PECO, SNEG, WEGU	BLPH

* 11/10/19 – No birds flushed.
*12/1/19 – No biological data collected.

AMCO – American coot, **AMCR** – American crow, **AMRO** – American robin, **AMWI** – American whimbrel, **BARS** – Barn swallow, **BHCO** – Brown-headed cowbird, **BLOY** – Black oystercatcher, **BLPH** – Black phoebe, **BRAC** – Brand's cormorant, **BRAN** – Brant, **BRBL** – Brewer's blackbird, **BRPE** – Brown pelican, **CAGU** – California Gull, **CCGO** – Canada goose, **CLSW** – Cliff swallow, **CORA** – Common raven, **GBHE** – Great blue heron, **GREG** – Great egret, **GRHE** – Green heron, **KILL** – Killdeer, **MALL** – Mallard, **NOHA** – Northern harrier, **NOMO** – Northern mockingbird, **PECO** – Pelagic cormorant, **PIGU** – Pigeon guillemot, **RNPH** – Red-necked phalarope, **RSHA** – Red-shouldered hawk, **RWBL** – Red-winged blackbird, **SAND** – Sanderling, **SAPH** – Say's phoebe, **SNEG** – Snowy Egret, **SOSP** – Song sparrow, **TUVU** – Turkey vulture, **WEGU** – Western gull, **WESA** – Western sandpiper

UC Santa Cruz NOID 12 (20-1)

SCZ-NOID-0004-20

Special Conditions Implementation Report 3

January 1, 2022 – June 30, 2022

Burrowing owl on the Younger Lagoon Reserve Beach Dunes

UC Santa Cruz NOID 12 (20-1)
Special Conditions Implementation Report 3

Overview and Executive Summary

On October 7, 2020, the California Coastal Commission approved UC Santa Cruz's NOID 12 (20-1) as consistent with UC Santa Cruz's approved Coastal Long Range Development Plan with the addition of new requirements supplementing the existing (NOID 9 18-1) five staff-recommended special conditions. The five special conditions included 1) Free Beach Tours, 2) Beach Tour Outreach Plan, 3) Beach Tour Signs, 4) Beach Tour Availability and Monitoring, and 5) Beach Access Management Plan Duration. Within 30 days of the approval (i.e., by November 7, 2020), UC Santa Cruz was required to submit a plan for implementation of special condition 2 (Outreach Plan) to the Executive Director of the California Coastal Commission. The plan for implementation of the special conditions was submitted to the Executive Director of the California Coastal Commission on November 5, 2020 and approved as submitted. Special condition 4 requires that at least every six months (i.e., by June 30th and December 31st each year), UC Santa Cruz shall submit two copies of a Beach Tour Monitoring Report for Executive Director review and approval. UC Santa Cruz's report on the implementation of these special conditions for the period of July 1, 2021 through December 31, 2021 is detailed below. UC Santa Cruz has included information from the previous four reporting periods covered under NOID 9 (18-1) and one-year prior, to provide historical and cumulative reference data. This is the third report under NOID 12 (20-1). The next report under NOID 12 (20-1) is due by December 31, 2022.

A summary of UC Santa Cruz's compliance with the five special conditions is below. Due to the COVID-19 pandemic - and in response to UC Santa Cruz's request for a COVID-19 emergency waiver, on July 10, 2020 the Commission issued a permit waiver to UC Santa Cruz's in support of COVID-19-related temporary closures and free beach tour suspensions (see UC Santa Cruz's Pub. Res. Code section 30611 notification letter to the Commission dated July 6, 2020). The Seymour Center was temporarily closed and the free beach tour program temporarily suspended in early March 2020. As requested by Commission staff, UC Santa Cruz's notified the Commission in May 2021 and May 2022 of the University's phased reopening efforts. The Seymour Center partially reopened with some limited outdoor programming in summer 2021, the Exhibit Hall reopened in October 2021, and the free beach tour program restarted in April 2022. Despite achieving this huge accomplishment in the wake of the pandemic, the Seymour Center still faces significant challenges including severe staffing shortages and competing priorities for continued reopening operations. The challenges contributed to the limited outreach of the free beach tour program during this reporting period. Despite the limited outreach during this reporting period, the tours have been well attended since April 2022. Total tour attendance for the 2022 tours that have been offered thus far was more than 200% higher than tour attendance during the same time period in 2019 and more than 180% higher than tour attendance during the same time period in 2018.

Within the next six months, the Seymour Center intends to have limited, part-time student assistants and interns in the Seymour Center's education department assist with outreach until a full-time Marketing Director is hired. The Marketing Director is anticipated to be hired before the end of the calendar year 2022 and shall be fully responsible for all outreach, marketing, and advertising efforts, including fulfilling the outreach requirements of the free beach tours, as part of NOID 12 special conditions. Once the new full-time Marketing Director is onboarded, UC Santa Cruz assumes all of the outreach requirements for the free beach tours shall be fulfilled.

Special Condition	Status	Notes
1) Free Beach Tours	Completed	All beach tours are offered for free without admission to the Seymour Center.
2) Beach Tour Outreach Plan	Completed & Ongoing	UC Santa Cruz's Updated Beach Tour Outreach Plan was approved by the Executive Director in November 2020 and all beach tour outreach materials now clearly state that the beach tour is free. Upon hiring of the Seymour Center Marketing Director, UC Santa Cruz's ongoing outreach efforts will include regular social media postings and calendar listings, including listings in Spanish and publications that serve inland communities.
3) Beach Tour Signs	Completed	UC Santa Cruz's Beach Tour Signage Plan under NOID 9 (18-1) was approved by the executive director in January 2019 and "Free Beach Tour" signs have been installed at all of the required locations.
4) Beach Tour Availability and Monitoring	Completed & Ongoing	With the exception of those tours canceled due to the pandemic, free beach tours are offered per the required schedule – a minimum of 38 times a year on weekends and weekdays, and all of the required data on tour attendees has been and will continue

		to be collected. UC Santa Cruz submitted all of the previously required biannual reports on the beach tours covered under NOID 9 (18-1) and NOID 12 (20-1) on-time. This is the third report under NOID 12 (20-1).
5) Beach Access Management Plan Duration	In Progress	NOID 12 (20-1) is effective through December 31, 2025. UC Santa Cruz is required to submit their next Beach Access Management Plan NOID by July 1, 2025.

Historical data from previous reports are provided below for context.

Implementation of the NOID 9 (18-1) special conditions resulted in an approximately 18% increase in overall tour participation and more than 900% increase in walk-in/day-of tour participants in 2019 (first full year post special conditions) compared to 2018 (pre special conditions).

A summary of the free beach tour user data for 2018 (pre special conditions) and 2019 (first full year post special conditions) is below:

Year	Dates	Total Tours Offered	Total Participants	Total # of Walk-in / Day-of Participants	Total # of Participants with a Reservation
2018	January 1-December 31	38	224	5	219
2019	January 1-December 31	38	265	46	219

Although only six tours were offered before the Seymour Center was temporarily closed and the free beach tour program temporarily suspended in early March 2020 due to COVID-19, total tour attendance for the 2020 tours that were offered was more than 100% higher than tour attendance during the same time period in 2019 and more than 350% higher than tour attendance during the same time period in 2018. A summary of the free beach tour user data for the first six tours in 2018 (pre special conditions), 2019 (first full year post special conditions), and 2020 is below:

Year	Dates	Total Tours Offered	Total Participants	Total # of Walk-in / Day-of Participants	Total # of Participants with a Reservation
2018	January 1-March 7	6	17	2	15
2019	January 1-March 4	6	31	6	25
2020	January 1-March 8	6	60	5	55

Although the tours were suspended during the same time period in 2022 (January-March 2022), attendance has been strong since the tours restarted in April 2022. Total tour attendance for the 2022 tours that have been offered thus far was more than 200% higher than tour attendance during the same time period in 2019 and more than 180% higher than tour attendance during the same time period in 2018. A summary of the free beach tour user data for the spring tours in 2018 (pre special conditions), 2019 (first full year post special conditions), and 2022 is below:

Year	Dates	Total Tours Offered	Total Participants	Total # of Walk-in / Day-of Participants	Total # of Participants with a Reservation
2018	April 5 – June 21	12	70	0	70
2019	April 4 - June 20	12	60	19	41
2022	April 7 - June 25	12	127	11	116

In order to maintain public access and engagement during the COVID-19 pandemic, the University created a virtual bilingual beach tour that is available on the Seymour Center and Younger Lagoon Reserve websites. Since its debut, the English language virtual tour has been viewed nearly 350 times and the Spanish language virtual tour has been viewed nearly 25 times. The virtual tour will continue to be offered post-pandemic and allows visitors from around the world to learn about the unique ecology and programs at the reserve in English and Spanish from the comfort of home or a mobile device.

The virtual tour websites feature a map of the reserve with marked locations where visitors can click to watch videos about the features of each type of habitat.

Virtual Tour Links:
English: https://arcg.is/11m1Ga
Spanish: https://arcg.is/0q0Czv

A UC Santa Cruz undergraduate student created the virtual tour websites and edited the videos as part of an internship project. This student completed all of the work on this project remotely, including learning about the reserve itself. A Younger Lagoon Reserve undergraduate student employee who assisted with the free in-person tours prior to the pandemic acts as the on-camera guide for both tours.

Condition 1.

FREE BEACH TOURS

All beach tours shall be offered for free, and UC Santa Cruz shall not require that beach tour users pay any separate admission fee to any other facility in order to take the beach tour. This condition shall not be construed as affecting existing, already-allowed admission fees for UC Santa Cruz's Seymour Marine Discovery Center. At a minimum, beach tour sign-ups shall be provided online (e.g., at UC Santa Cruz Marine Science Campus and Seymour Marine Discovery Center websites), by phone, and at the Seymour Marine Discovery Center front desk. UC Santa Cruz shall also identify and implement a mechanism for tracking the number of tour requests that are denied due to lack of tour availability or because tours are fully booked. All UC Santa Cruz materials referencing the beach at Younger Lagoon and/or beach tours shall be required to be modified as necessary to clearly identify that access to the beach is available for free via beach tours.

Implementation Report

Due to COVID-19 impacts, no free beach tours were offered during the first three months of 2022. Upon resumption of the tours, all beach tours were offered for free (without admission fee). Beach tour sign-ups are available online through the Seymour Marine Discovery Center (Seymour Center) website, by phone and at the Seymour Center public admissions counter. Seymour Center staff track any tour requests that are denied due to lack of tour availability or because tours are fully booked as part of their ongoing monitoring of all visitor programs. Seymour Center staff record the number of participants that were denied, the number of participants that were wait listed, as well as the date of the request, the date of the tour being requested, and how participants heard about the tour (see Condition 2). All UC Santa Cruz public materials referencing the beach at Younger Lagoon and/or beach tours, including the websites below, clearly identify that access to the beach is available for free. (Note that there is no UC Santa Cruz Marine Science Campus website; tour information has been posted to the Younger Lagoon Reserve and Seymour Marine Discovery Center websites, both of which were updated with new addresses during this reporting period; see below). Notice of the temporary cessation of the free beach tours during the first three months of 2022 due to COVID-19 was posted to the Younger Lagoon Reserve and the Seymour Marine Discovery Center websites.

https://youngerlagoonreserve.ucsc.edu/about-us/index.html

https://youngerlagoonreserve.ucsc.edu/research-teaching-public-service/visit/public-tours.html

(Note: this page has been replaced by the site below beginning in June 2022) https://youngerlagoonreserve.ucsc.edu/visit/public-tours.html

https://seymourcenter.ucsc.edu/visit/behind-the-scenes-tours/ (Note: this page has been replaced by the site below in June 2022)

https://seymourcenter.ucsc.edu/visit/groups-and-tours/

Condition 2.

BEACH TOUR OUTREACH PLAN

Within 30 days of this approval (i.e., by November 7, 2020), UC Santa Cruz shall submit two copies of an updated Outreach Plan for Executive Director review and approval, where such Plan shall identify all measures and venues to be used to advertise and increase awareness of the beach tours, including the online virtual tours. Promotional methods shall include, but are expected to not be limited to: UC Santa Cruz Marine Science Campus and Seymour Marine Discovery Center websites, press releases, calendar listings with UC Santa Cruz Events and local media (e.g., Good Times newspaper, Santa Cruz Sentinel, The Register-Pajaronian, The Half Moon Bay Review, The Monterey Herald, etc.), ads on radio (e.g., local radio stations KAZU, KRML, and others), print ads, social media (including Facebook, Twitter, and Instagram), and contacts with influential organizations in local environmental and community advocacy groups who may facilitate promotional opportunities. The Plan shall identify the language to be used in describing the virtual and free in-person beach tours (where said language shall be required to be consistent with the terms and conditions of this approval), and shall provide a schedule for each type of outreach, with the goal being to reach as many potential online viewers and potential beach tour participants as possible, including audiences beyond Santa Cruz that might not normally be reached through traditional and local means (e.g., inland communities). The Plan shall describe how UC Santa Cruz will monitor and track the Outreach Plan's execution so that UC Santa Cruz and the Coastal Commission can note the effectiveness of the plan and make changes as needed. UC Santa Cruz shall implement the updated approved Outreach Plan.

Implementation Report

Due to COVID-19 impacts, no free beach tours were offered during the first three months of 2022 and thus, no free beach tour outreach was conducted during those months. Upon resumption of the tours, limited outreach was conducted according to the following plan, which was approved by the Executive Director and includes all of the measures and venues described in Condition 2:

Venue	Language	Schedule	Mechanism for Monitoring and Tracking	
Seymour Center Website	Younger Lagoon Reserve tours are free and open to the public. Space is limited to 18	Permanent webpage: https://seymourcenter.ucsc.edu/	Provide link to updated website and date that updates were made	Webpage updated April 2022 & 6/1/22

	participants. Call **831-459-3800** or sign-up here*. Virtual tours are available here**. * hyperlink to online sign-up **hyperlink to virtual tour	visit/groups-and-tours/		Note that permanent webpage moved locations on 6/1/22.
YLR Website	Younger Lagoon Reserve tours are free and open to the public. Space is limited to 18 participants. Call **831-459-3800** or sign-up online. Virtual tours are available online. **seymourcenter.ucsc.edu**	Permanent webpage: https://youngerlagoonreserve.ucsc.edu/visit/public-tours.html	Provide link to updated website and date that updates were made	Webpage updated 3/31/22 & 6/1/22 Note that permanent webpage moved locations on 6/1/22.
Seymour Center Social Media • Facebook • Twitter • Instagram	Younger Lagoon Reserve tours are free and open to the public. Space is limited to 18 participants. Call **831-459-3800** or sign-up online. Virtual tours are available online. **seymourcenter.ucsc.edu**	Facebook—Monthly Twitter, Instagram --- Once a quarter	Document date that posts are made and capture a link to the post	Pending staff hiring; due to reopening staff shortages. Tours will be posted during the next reporting period.
YLR Social Media • Facebook • Instagram	Younger Lagoon Reserve tours are free and open to the public. Space is limited to 18 participants. Call **831-459-3800** or sign-up online. Virtual tours are available online. **seymourcenter.ucsc.edu**	Once a quarter	Document date that posts are made and capture a link to the post	Facebook posted, 3/31/22 Instagram posted, 3/30/22
Calendar Listings • UC Santa Cruz Events	Younger Lagoon Reserve tours are free and open to the public. Space is limited to 18	Submitted monthly (calendar listings appear at the discretion	Document date that listings are submitted, and verify that the listing ran by	Pending staff hiring; due to reopening staff shortages. Calendar listings

• Good Times Newspaper (Santa Cruz) • Register Pajaronian Newspaper (Watsonville) • The Half Moon Bay Review • The Monterey Herald • KAZU public radio (Santa Cruz) • KRML (Monterey Bay)	participants. Call **831-459-3800** or sign-up online. Virtual tours are available online. **seymourcenter.ucsc.edu** For Spanish language outlets: Las visitas guiadas a la reserva de la laguna Younger son gratuitas y están abiertas al público. El espacio está limitado a 18 participantes. Llame al **831-459-3800** o regístrese en línea. Las visitas virtuales están disponibles en línea. **seymourcenter.ucsc.edu**	of the media outlet.)	capturing a link to the website (if online)	will be submitted when the Seymour Center's Marketing Director is hired.
Ads • Santa Cruz Sentinel Newspaper (Santa Cruz) • Good Times Newspaper (Santa Cruz) • KAZU public radio (Santa Cruz)	Younger Lagoon Reserve tours are free and open to the public. Space is limited to 18 participants. Call **831-459-3800** or sign-up online. Virtual tours are available online. **seymourcenter.ucsc.edu** For Spanish language outlets: Las visitas guiadas a la reserva de la laguna Younger son gratuitas y están abiertas al público. El espacio está limitado a 18	Quarterly	Document date that ads ran, and verify that the ad ran by capturing a link to the website (if online)	Pending staff hiring; due to reopening staff shortages. Ads will be submitted when the Seymour Center's Marketing Director is hired.

	participantes. Llame al **831-459-3800** o regístrese en línea. Las visitas virtuales están disponibles en línea. **seymourcenter.ucsc.edu**			
Press Release	Younger Lagoon Reserve tours are free and open to the public. Space is limited to 18 participants. Call **831-459-3800** or sign-up online. Virtual tours are available online. **seymourcenter.ucsc.edu** For Spanish language outlets: Las visitas guiadas a la reserva de la laguna Younger son gratuitas y están abiertas al público. El espacio está limitado a 18 participantes. Llame al **831-459-3800** o regístrese en línea. Las visitas virtuales están disponibles en línea. **seymourcenter.ucsc.edu**	Announce the virtual tours and resumption of free in-person beach tours post-COVID via two bilingual (English and Spanish) UC Santa Cruz press releases.	Document the date of the press releases, distribution list of media outlets and verify that the press releases were posted by capturing a link to the website (if online).	Posted 6/1/22 Distributed to: • UC Santa Cruz Events • Good Times Newspaper (Santa Cruz) • Register Pajaronian Newspaper (Watsonville) • The Half Moon Bay Review • The Monterey Herald • KAZU public radio (Santa Cruz) • KRML (Monterey Bay)
Contacts who may facilitate promotional opportunities • SMDC Educator Email Mailing List (815	Younger Lagoon Reserve tours are free and open to the public. Space is limited to 18 participants. Call **831-459-3800** or sign-up online. Virtual tours are	Once a quarter	Information about the tours will be emailed to contacts once a quarter. Date of email and recipients will be documented.	Information was sent to the Seymour Center E-newsletter on the following dates: 3/18/2022 4/1/2022

subscribers) • Homeschool Mailing Email List (124 subscribers) • Seymour Center E-newsletter list - 10,000 email recipients from all over California and beyond • UC Santa Cruz Events Email-newsletter • Andy Carman at Enviroteers, weekly newsletter • CSUMB Outdoor Recreation Resources and Opportunities Website • Outdoor World Outdoor Resources Website: https://www.theoutdoorworld.com/info/outdoor-resources	available online. **seymourcenter.ucsc.edu** For Spanish language outlets: Las visitas guiadas a la reserva de la laguna Younger son gratuitas y están abiertas al público. El espacio está limitado a 18 participantes. Llame al **831-459-3800** o regístrese en línea. Las visitas virtuales están disponibles en línea. **seymourcenter.ucsc.edu**			4/14/2022 5/4/2022 5/20/2022 6/3/2022 6/16/2022 No other contacts were provided information about the tours during the reporting period due to reopening impacts. Contacts will be provided with tour information when the Seymour Center's Marketing Director is hired

In addition, tour participants were surveyed to determine how they heard about the tour. This information is tracked with sign-up information (see Condition 1). To date, the majority of tour participants learned about the free beach tour through the Seymour Center's newsletter and/or a friend (Figure 1).

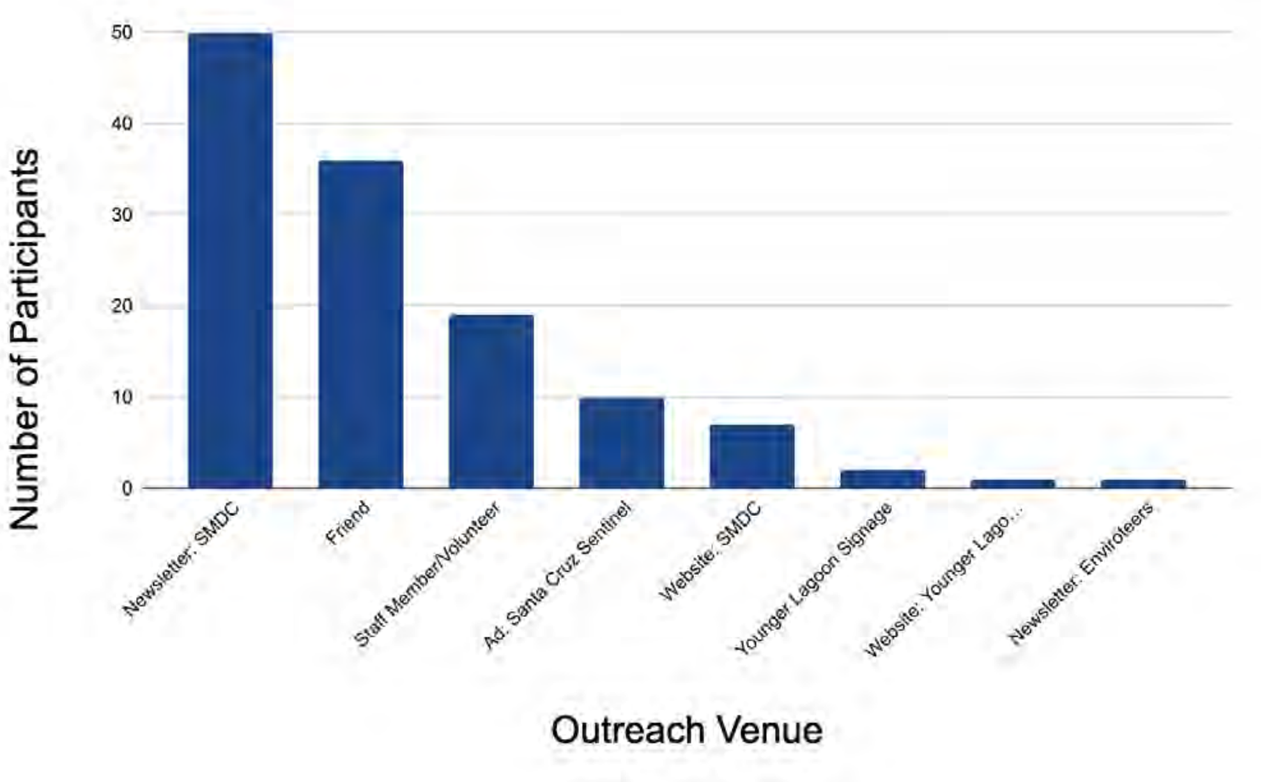

Figure 1. Outreach survey results for the Spring 2022 free beach tours (N=127).

Condition 3.

BEACH TOUR SIGNS

UC Santa Cruz will continue to implement the Beach Tour Sign Plan that was previously-approved by the Executive Director under NOID 9 where such Plan has provided for installation of signage outside of the Seymour Marine Discovery Center and inside at its front desk, at Campus overlooks, and at other appropriate public access locations on the Marine Science Campus that describe free beach tour availability, including "day of" signs for each day beach tours are offered to ensure maximum notice is provided. All such signs shall continue to be sited and designed to be visually compatible with the area, consistent with the Campus sign program (and CLRDP sign requirements) *and continue to provide clear information in a way that minimizes public view impacts. UC Santa Cruz shall continue to implement the approved Beach Tour Sign Plan from NOID 9.*

Implementation Report

Due to COVID-19 impacts, no free beach tours were offered during the first three months of 2022. Upon resumption of the tours, information on the free beach tours was displayed "day of" on large sign in the front window of the Seymour Center and at the public admissions counter. Admissions counter signage will continue to include the brown and white footprints on wave logo, and include the following language "Free Younger Lagoon Reserve Beach Tours Today" (Figures 2, 5, and 6). Signage will continue to be displayed at the information kiosk outside (Figure 4) of the Seymour Center and at Overlooks A-F (Figures 7-13).

Note, Overlook B was renamed Terrace Point Overlook, as shown on a new coastal access sign installed as a condition of Overlook B Path Repair and Replacement (SCZ-NOID-0004-19), see below.

Overlooks, admissions counter, and kiosk signage includes the brown and white footprints on wave logo, and include the following language "Free Younger Lagoon Reserve Beach Tours, Call (831) 459-3800" (Figure 3).

Figure 2. "Day of" sign design.

Figure 3. Overlooks and kiosk sign design.

Figure 4. Signage installed at Seymour Center information kiosk (photo taken pre-pandemic).

Figure 5. Signage installed at Seymour Center front window (photo taken pre-pandemic).

Figure 6. Signage installed at the Seymour Center admissions desk (photo taken pre-pandemic).

Figure 7. Signage installed at Overlook A.

Figure 8. Signage installed at Overlook A (close-up).

Figure 9. Signage installed at Overlook B (Terrace Point).

Figure 10. Signage installed at Overlook C.

Figure 11. Signage installed at Overlook D.

Figure 12. Signage installed at Overlook E.

Figure 13. Signage installed at Overlook F.

Condition 4.

BEACH TOUR AVAILABILITY AND MONITORING

UC Santa Cruz shall offer at least four beach tours per month (of which at least one per month is a weekday tour and at least two per month are weekend tours) from March 1st through September 30th each year and shall provide at least two beach tours per month (of which at least one per month is a weekday tour and at least one per month is a weekend tour) otherwise (totaling a minimum of 38 total beach tours per year). UC Santa Cruz may limit the number of beach tour participants to 18 persons per tour, but this number may be exceeded per tour on a case-by-case basis, and beach tours shall not require any minimum number of participants to be provided (i.e., if at least one person signs up, the tour shall be provided). UC Santa Cruz shall document the date/time and number of participants for each beach tour, as well as the number of tour requests that are denied due to lack of tour availability or because tours are fully booked (see also Condition 1).

At least every six months (i.e., by June 30 and December 31 of each year), UC Santa Cruz shall submit two copies of a Beach Tour Monitoring Report for Executive Director review and approval, where the Report shall, at a minimum, provide information regarding compliance with these conditions of approval, including a section identifying UC Santa Cruz's activities under the approved updated Beach Tour Outreach Plan (see Condition 2) and which shall include specific information regarding the dates that each advertisement for beach tours was placed in each venue/media/social media outlet, as well as the required information described in the previous paragraph. Each such Monitoring Report shall include a section that identifies recommendations about whether user data suggests that beach tours should be increased in terms of frequency of tours and/or number of tour attendees, or otherwise modified to better respond to user demand, including the potential to offer a more limited beach area tour (e.g., designed to allow participants to access just the sandy beach area itself in a shorter amount of time) as a means of offsetting demand. Each Monitoring Report shall also include a section that describes how the beach-lagoon ecosystem has responded to beach tours. This assessment will include data and analysis useful for assessing whether the ecosystem shows any impacts from beach tours. This assessment will be used to help determine if larger tours have any impacts on the YLR ecosystem, its environmental quality, and UC Santa Cruz research opportunities at the site. UC Santa Cruz shall implement any Executive Director-approved recommendations from each Beach Tour Monitoring Report.

Implementation Report

Due to COVID-19 impacts, no free beach tours were offered during the first three months of 2022 and no data were collected. Upon resumption of the tours in April 2022, free beach tours were offered four times per month on select Thursdays and Saturdays. Tours will continue to be offered at least four times per month (at least one on a weekday and two on a weekend tours) from March 1st through September 30th each year, and will be offered at least two times per month (at least one on a weekday and one on a weekend) for the remainder of the year (a minimum of 38 total beach tours per year). Beach tour participants were limited to 18 persons per tour, but this number may be exceeded per tour on a case by case basis, and beach tours did not require any minimum number of participants to be provided (i.e., if at least one person signs up, the tour is provided). UC Santa Cruz has documented the date/time and number of participants for each beach tour, as well as the number of tour requests that are denied due to lack of tour availability or because tours are fully booked (see also Condition 1). In addition, tour participants were surveyed to determine how they heard about the tour. This information is being tracked with sign-up information (see Conditions 1 and 2).

At least every six months (i.e., by June 30th and December 31st each year), UC Santa Cruz will submit two copies of a Beach Tour Monitoring Report for Executive Director review and approval, where the Report will at a minimum provide information regarding compliance with these conditions of approval, including a section identifying UC Santa Cruz's activities under the approved updated Beach Tour Outreach Plan (see Condition 2), as well as the required information described in the previous paragraph and Condition 4 above. This is the third such report under this implementation plan and has been submitted by June 30, 2022.

Due to COVID-19 impacts, a total of 12 free beach tours (127 participants) were offered during the spring of 2022 (See Appendix 1). Participants were limited to 18 persons per tour on tours and all tours had at least one participant. Three of the tours that went out included walk-in / "day-of" participants. Six tours were overbooked during the reporting period.

In comparison, UC Santa Cruz offered 12 beach tours (70 participants) during the spring of 2018 (Appendix 2; pre special conditions). Two tours did not go out due to lack of sign-ups. None of the tours that went out in the spring of 2018 included walk-in / "day-of" participants. No tours were overbooked during the spring of 2018.

Although not required by the special conditions, in addition to tracking user data, UC Santa Cruz also collected data on the biological impacts of the tours. Beginning on April 14, 2019, Younger Lagoon Reserve staff accompanied tours, and documented impacts to avian wildlife on the beach. Staff observed birds flushing from the wet sandy beach, beach dunes, coastal stack, and lagoon in response to all but three of the tours they attended (see Appendix 3). The average number of avian species present post-tour was significantly less than the average number of avian species pre-tour (p=.0007, paired t-test; See Figure 13).

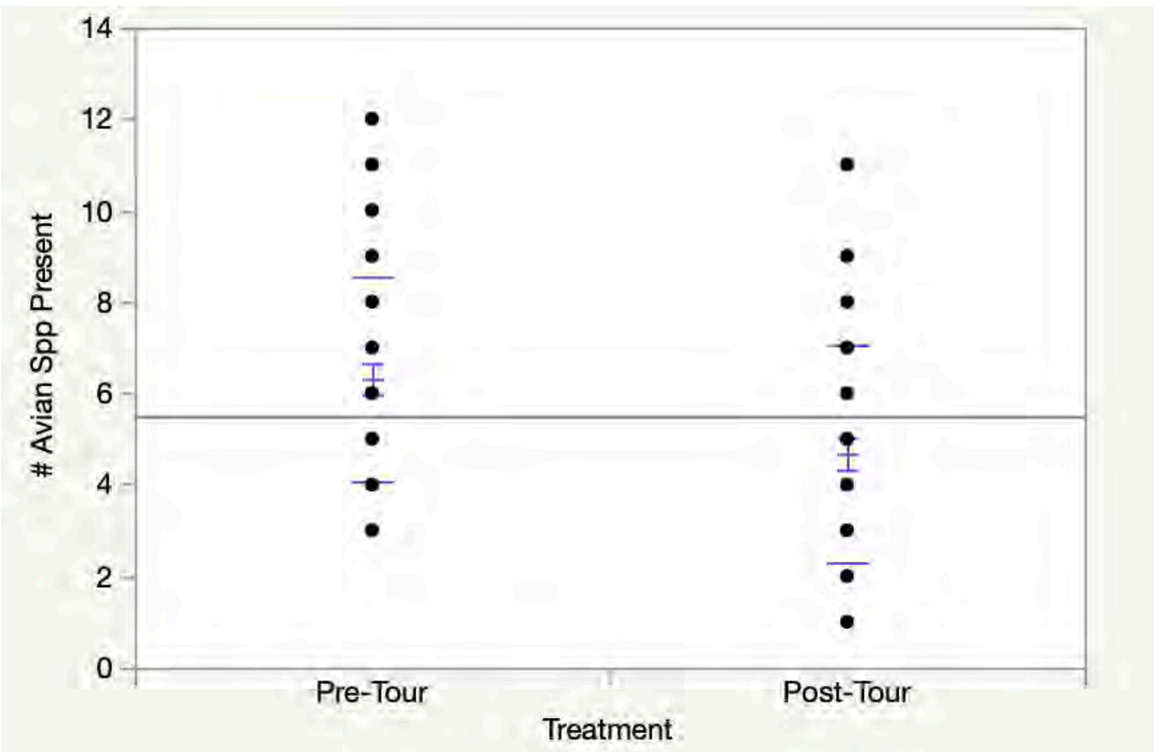

Figure 13. Effect of tours on avian species. Blue I-bars indicate mean, standard error, and standard deviation. The average number of avian species present pre-tour was 6.31 +/- 2.24 (+/- sd). The average number of avian species present post-tour was 4.68 +/- 2.38 (+/- sd). The average number of avian species present post-tour was significantly less than the average number of avian species pre-tour (p=.0007, paired t-test).

Recommendations

Although only in place for 36 months and temporarily suspended for nearly two years due to COVID-19 impacts, the beach tours as specified by UC Santa Cruz's NOIDs 9 (18-1) and 12 (20-1) special conditions appear to be meeting user demand. Total tour attendance for the 2022 tours that were offered was more than 200% higher than tour attendance during the same time period in 2019 (first full year post special conditions) and more than 180% higher than tour attendance during the same time period in 2018 (pre special conditions). During the 24 months covered by NOID 9 (18-1), eight participants were denied a tour due to overdemand. During the three months since the free beach tours resumed in April 2022, 27 participants were denied a tour due to overdemand. UC Santa Cruz staff feel this is likely a result of post-COVID pent up demand, the relative safety of this entirely outdoor offering, and the fact that the free beach tour is the first (and to date, only) of the Seymour Center's docent-guided tours to restart post-pandemic. UC Santa Cruz will continue to monitor tour demand as the pandemic wanes and Seymour Center operations and offerings ramp back up. NOID 12 (20-1) continued the five NOID 9 special conditions, increased the upper limit of tour attendees and required additional outreach efforts.

The documented negative biological impacts to avian wildlife described above, along with ongoing quarterly beach monitoring efforts indicate that open and unsupervised access to the beach would result in the loss of the unique ecological characteristics of the site, reduce its effectiveness as a research area for scientific study, and likely have a negative impact on sensitive and protected species (See 2009-2010, 2010-2011, 2011-2012, 2012-2013, 2013-2014, 2014-2015, 2015-2016, 2016-2017, 2017-2018, 2018-2019, 2019-2020, and 2020-2021 Annual Reports).

We recommend that the balance between resource protection of the beach and lagoon area – all of which are considered Environmentally Sensitive Habitat Area (ESHA) or ESHA buffer by the Commission, and public access continue to be carefully evaluated and managed. Although similar in many ways to other local pocket beaches, Younger Lagoon beach supports a unique assemblage of flora and fauna, including rare and endangered species. As part of the UC Natural Reserve System, Younger Lagoon Reserve acts as a protected living laboratory and outdoor classroom for teaching and research and is managed in trust for the people of the State of California by the University.

Condition 5.

BEACH ACCESS MANAGEMENT PLAN DURATION

This approval for UC Santa Cruz's public beach access management plan at Younger Lagoon Beach shall be effective through December 31, 2025. UC Santa Cruz shall submit a complete NOID, consistent with all CLRDP requirements, to implement its next public beach access management plan at Younger Lagoon Beach (for the period from January 1, 2026 to December 31, 2030) no later than July 1, 2025. Such a complete NOID shall, at a minimum, summarize the results of the Beach Tour Monitoring Reports (see Condition 4), and shall identify the manner in which UC Santa Cruz's proposed management plan responds to such data, including with respect to opportunities to increase public access to the beach area when considered in light of potential impacts to UC Santa Cruz research and coastal resources. If such a complete NOID has not been submitted by July 1, 2025, then UC Santa Cruz shall allow supervised (via beach and trail monitors only) general public access to Younger Lagoon Beach during daylight hours (i.e., one hour-before sunrise to one-hour after sunset) until such NOID has been submitted.

Implementation Report

UC Santa Cruz will submit a complete NOID, consistent with all CLRDP requirements, to implement its next public beach access management plan at Younger Lagoon Beach (for the period from January 1, 2026 to December 31, 2030) no later than July 1, 2025.

Appendix 1. Tour Data January 1, 2022 – June 30, 2022

Tour Date	Day	Participants	Walk in	Reservation	No Show	Denial / Wait list
1/2/22*	Thursday	-	-	-	-	-
1/8/22*	Saturday	-	-	-	-	-
2/3/22*	Thursday	-	-	-	-	-
2/12/22*	Saturday	-	-	-	-	-
3/3/22*	Thursday	-	-	-	-	-
3/12/22*	Saturday	-	-	-	-	-
3/17/22*	Thursday	-	-	-	-	-
3/26/22*	Saturday	-	-	-	-	-
4/7/22	Thursday	4	0	4	0	0
4/9/22	Sunday	4	0	4	0	0
4/21/22	Thursday	8	0	8	0	0
4/23/22	Saturday	5	0	5	0	0
5/5/22	Thursday	1	0	7	6	0
5/14/22	Saturday	18	2	16	2	0
5/19/22**	Thursday	11	0	18	7	2
5/28/22***	Saturday	13	4	18	9	3
6/2/22****	Thursday	18	0	18	0	3
6/11/22*****	Saturday	18	5	18	5	10
6/16/22******	Thursday	17	0	18	1	2
6/25/22*******	Saturday	10	0	18	8	9

*1/6/22 - 3/26/22 – Canceled due to COVID-19 impacts.
**5/19/22 - Denial due to overdemand; participants accommodated on future date.
***5/28/22 - Denial due to overdemand; three participants signed up for the waitlist as well as a future date. Two of the three walked in on 5/28 and were able to get a spot when others no showed.
****6/2/22 - Denial due to overdemand; participants accommodated on future date.
*****6/11/22 - Denial due to overdemand; participants accommodated on future date.
******6/16/22 - Denial due to overdemand; participants were directed to the website to sign up for a future date.
*******6/25/22 - Denial due to overdemand; participants were put on the waitlist due to full reservations and were not able to make it in time to join the tour after a larger group no-showed.

Appendix 1 (cont.). Tour Data July 1, 2021 – December 31, 2021

Tour Date	Day	Participants	Walk in	Reservation	No Show	Denial / Wait list
7/1/21*	Thursday	-	-	-	-	-
7/11/21*	Sunday	-	-	-	-	-
7/15/21*	Thursday	-	-	-	-	-
7/25/21*	Sunday	-	-	-	-	-
8/5/21*	Thursday	-	-	-	-	-
8/8/21*	Sunday	-	-	-	-	-
8/19/21*	Thursday	-	-	-	-	-
8/22/21*	Sunday	-	-	-	-	-
9/2/21*	Thursday	-	-	-	-	-
9/12/21*	Sunday	-	-	-	-	-
9/16/21*	Thursday	-	-	-	-	-
9/26/21*	Sunday	-	-	-	-	-
10/7/21*	Thursday	-	-	-	-	-
10/10/21*	Sunday	-	-	-	-	-
11/4/21*	Thursday	-	-	-	-	-
11/14/21*	Sunday	-	-	-	-	-
12/2/21*	Thursday	-	-	-	-	-
12/5/21*	Sunday	-	-	-	-	-

*7/1/21 - 12/5/21 – Canceled due to COVID-19 impacts.

Appendix 1 (cont.). Tour Data January 1, 2021 – June 30, 2021

Tour Date	Day	Participants	Walk in	Reservation	No Show	Denial / Wait list
1/7/21*	Thursday	-	-	-	-	-
1/10/21*	Sunday	-	-	-	-	-
2/4/21*	Thursday	-	-	-	-	-
2/14/21*	Sunday	-	-	-	-	-
3/4/21*	Thursday	-	-	-	-	-
3/14/21*	Sunday	-	-	-	-	-
3/18/21*	Thursday	-	-	-	-	-
3/28/21*	Sunday	-	-	-	-	-
4/1/21*	Thursday	-	-	-	-	-
4/11/21*	Sunday	-	-	-	-	-
4/15/21*	Thursday	-	-	-	-	-
4/25/21*	Sunday	-	-	-	-	-
5/6/21*	Thursday	-	-	-	-	-
5/9/21*	Sunday	-	-	-	-	-
5/20/21*	Thursday	-	-	-	-	-
5/23/21*	Sunday	-	-	-	-	-
6/3/21*	Thursday	-	-	-	-	-
6/13/21*	Sunday	-	-	-	-	-
6/17/21*	Thursday	-	-	-	-	-
6/27/21*	Sunday	-	-	-	-	-
2021 TOTAL	-	-	-	-	-	-

*1/7/21 - 6/27/21 – Canceled due to COVID-19 impacts.

Appendix 1 (cont.). Tour Data July 1, 2020 – December 31, 2020

Tour Date	Day	Participants	Walk in	Reservation	No Show	Denial / Wait list
7/2/20*	Thursday	-	-	-	-	-
7/12/20*	Sunday	-	-	-	-	-
7/16/20*	Thursday	-	-	-	-	-
7/26/20*	Sunday	-	-	-	-	-
8/6/20*	Thursday	-	-	-	-	-
8/9/20*	Sunday	-	-	-	-	-
8/20/20*	Thursday	-	-	-	-	-
8/23/20*	Sunday	-	-	-	-	-
9/3/20*	Thursday	-	-	-	-	-
9/13/20*	Sunday	-	-	-	-	-
9/17/20*	Thursday	-	-	-	-	-
9/27/20*	Sunday	-	-	-	-	-
10/1/20*	Thursday	-	-	-	-	-
10/11/20*	Sunday	-	-	-	-	-
11/5/20*	Thursday	-	-	-	-	-
11/8/20*	Sunday	-	-	-	-	-
12/3/20*	Thursday	-	-	-	-	-
12/6/20*	Sunday	-	-	-	-	-

*7/2/20 - 12/6/20 – Canceled due to COVID-19 impacts.

Appendix 1 (cont.). Tour Data January 1, 2020 – June 30, 2020

Tour Date	Day	Participants	Walk in	Reservation	No Show	Denial / Wait list
1/2/20	Thursday	15	4	20	9	0
1/12/20	Sunday	13	1	18	6	0
2/6/20	Thursday	9	0	18	9	0
2/9/20	Sunday	4	0	5	1	0
3/5/20	Thursday	8	0	8	0	0
3/8/20	Sunday	11	0	14	3	0
3/19/20*	Thursday	-	-	-	-	-
3/22/20*	Sunday	-	-	-	-	-
4/2/20*	Thursday	-	-	-	-	-
4/5/20*	Sunday	-	-	-	-	-
4/16/20*	Thursday	-	-	-	-	-
4/26/20*	Sunday	-	-	-	-	-
5/7/20*	Thursday	-	-	-	-	-
5/10/20*	Sunday	-	-	-	-	-
5/21/20*	Thursday	-	-	-	-	-
5/24/20*	Sunday	-	-	-	-	-
6/4/20*	Thursday	-	-	-	-	-
6/14/20*	Sunday	-	-	-	-	-
6/18/20*	Thursday	-	-	-	-	-
6/28/20*	Sunday	-	-	-	-	-
2020 TOTAL	**-**	**60**	**5**	**83**	**28**	**0**

*3/19/20 - 6/28/20 – Canceled due to COVID-19 impacts.

Appendix 1 (cont.). Tour Data January 1, 2019 – June 30, 2019

Tour Date	Day	Participants	Walk in	Reservation	No Show	Denial / Wait list
1/3/19	Thursday	2	2	0	0	0
1/13/19	Sunday	7	0	7	0	0
2/7/19	Thursday	3	0	3	0	0
2/10/19	Sunday	6	1	5	0	0
3/3/19	Sunday	10	3	7	0	0
3/719	Thursday	3	0	4	1	0
3/1019	Sunday	9	6	3	0	0
3/2119	Thursday	3	0	4	1	0
4/4/19	Thursday	10	6	4	0	0
4/7/19	Sunday	9	4	5	0	0
4/14/19	Sunday	9	2	11	4	0
4/18/19	Thursday	5	1	5	1	0
5/2/19	Thursday	1	0	1	0	0
5/5/19*	Sunday	0	0	0	0	0
5/12/19	Sunday	2	0	2	0	0
5/16/19	Thursday	1	0	1	0	0
6/2/19	Sunday	3	0	3	0	0
6/6/19	Thursday	1	1	0	0	0
6/9/19**	Sunday	16	4	14	0	2
6/20/19	Thursday	3	1	2	0	0

*5/5/19 - No tour; no participants.

**6/9/19 - Denial due to overdemand; participants accommodated on a Seymour Center daily tour, which included vistas of the lagoon and beach, later that day.

Appendix 1 (cont.). Tour Data July 1, 2019 – December 31, 2019

Tour Date	Day	Participants	Walk in	Reservation	No Show	Denial / Wait list
7/7/19	Sunday	14	4	13	3	0
7/11/19	Thursday	14	2	12	0	0
7/14/19	Thursday	17	5	18	6	0
7/18/19	Thursday	12	2	13	3	0
8/1/19	Thursday	10	0	18	8	0
8/4/19*	Sunday	14	0	21	1	6
8/11/19	Sunday	10	0	10	0	0
8/15/19	Thursday	5	0	5	0	0
9/1/19	Sunday	13	0	14	1	0
9/5/19	Thursday	6	0	6	0	0
9/8/19	Sunday	4	0	4	0	0
9/19/19	Thursday	2	0	2	0	0
10/3/19	Thursday	7	2	5	0	0
10/13/19	Sunday	9	0	9	0	0
11/7/19	Thursday	6	0	6	0	0
11/10/19	Sunday	8	0	13	5	0
12/1/19	Sunday	2	0	11	9	0
12/9/19	Thursday	9	0	9	0	0
2019 TOTAL	**-**	**265**	**46**	**270**	**43**	**8**
GRAND TOTAL	**-**	**325**	**51**	**353**	**71**	**8**

*8/4/19 - Denial due to overdemand. Participants offered a Seymour Center daily tour, which includes vistas of the lagoon and beach.

Appendix 2. Tour Data January 1, 2018 – June 30, 2018 (pre special conditions)

Tour Date	Day	Participants	Walk in	Reservation	No Show
1/4/18	Thursday	3	1	2	0
1/14/18	Sunday	3	0	3	0
2/1/18	Thursday	6	0	6	0
2/11/18	Sunday	2	1	1	0
3/1/18*	Thursday	1	0	1	0
3/4/18	Sunday	2	0	2	0
3/11/18	Sunday	6	1	5	0
3/15/18	Thursday	2	2	0	0
4/5/18	Thursday	11	0	11	0
4/8/18	Sunday	2	0	2	0
4/19/18	Thursday	8	0	8	0
4/22/18	Sunday	2	0	3	1
5/3/18	Thursday	11	0	11	0
5/6/18	Sunday	7	0	7	0
5/13/18	Sunday	2	0	2	0
5/17/18**	Thursday	0	0	0	0
6/3/18	Sunday	0	0	0	0
6/7/18	Thursday	10	0	11	1
6/10/18	Sunday	7	0	7	0
6/21/18	Thursday	10	0	13	3

*3/1/18 – Canceled due to weather.
**5/17/18 – Canceled; no sign-ups.
***6/3/18 – Canceled; no sign-ups.

Appendix 2 (cont.). Tour Data July 1, 2018 – December 31, 2018 (pre special conditions)

Tour Date	Day	Participants	Walk in	Reservation	No Show
7/1/18	Sunday	9	0	11	2
7/5/18	Thursday	13	0	13	0
7/8/18	Sunday	9	0	10	1
7/19/18*	Sunday	0	0	0	0
8/2/18**	Thursday	0	0	0	0
8/5/18	Sunday	13	0	15	2
8/12/18	Sunday	2	0	2	0
8/16/18	Thursday	9	0	9	0
9/2/18	Sunday	18	0	18	0
9/6/18	Thursday	6	0	6	0
9/9/18	Sunday	5	0	5	0
9/27/28	Thursday	14	0	15	1
10/4/18	Thursday	10	0	12	2
10/14/18	Sunday	8	0	8	0
11/1/18***	Thursday	0	0	0	0
11/11/18	Sunday	7	0	7	0
12/2/18	Sunday	6	0	8	2
12/6/18****	Thursday	0	0	0	0
2018 TOTAL	**-**	**224**	**5**	**234**	**15**

*7/19/18 – Canceled; no sign-ups.
**8/2/18 – Canceled; no sign-ups.
***11/1/18– Canceled; no sign-ups.
****12/6/18– Canceled; no sign-ups.

Appendix 3. Avian Wildlife Impact Data, January 1, 2022 – June 30, 2022

Tour Date	Day	Species Present	Species Flushed
1/2/22*	Thursday	-	-
1/8/22*	Saturday	-	-
2/3/22*	Thursday	-	-
2/12/22*	Saturday	-	-
3/3/22*	Thursday	-	-
3/12/22*	Saturday	-	-
3/17/22*	Thursday	-	-
3/26/22*	Saturday	-	-
4/7/22**	Thursday	AMCO, BRCO, CAGO, CAGU, MALL	-
4/9/22**	Sunday	AMWI, BRCO, CAGO, MALL, PIGU, WEGU, WHIM	-
4/21/22**	Thursday	AMWI, BRCO, CAGO, MALL, PIGU, WEGU, WHIM	-
4/23/22**	Saturday	BASW, BRCO, BLPH, CAGO, CORA, MALL, WEGU, SNEG, WHIM	-
5/5/22**	Thursday	BLPH, BRCO, CAGO, CAGU, KILL, PECO, WEGU -	KILL
5/14/22**	Saturday	GBHE, BRCO, PECO, WEGU, RTHA, MALL, YELE, RNFA, WHIM, PIGU, WEGU	-
5/19/22**	Thursday	BASW, BLPH, BRCO, BRPE, PIGU, VGSW, WEGU	-
5/28/22	Saturday	WEGU, BRCO, PECO, BASW, TUVU, AMCR, BRPE, PIGU, BLPH	TUVU
6/2/22	Thursday	BRCO, BRPE, WEGU	BRPE, WEGU
6/11/22	Saturday	BLPH, BRCO, CAGU, CORA, DCCO, HEGU, WEGU	BLPH, CAGU, WEGU
6/16/22	Thursday	BASW, BLPH, BRCO, CAGU, CLSW, COMU, PECO, PIGU, WEGU	WEGU
6/25/22	Saturday	BASW, BLPH, BRCO, PIGU, SASP, SASP, WEGU	WEGU

*1/6/22 - 3/26/22 – Canceled due to COVID-19 impacts. No biological data collected.
** 4/7/22, 4/9/22, 4/21/22, 4/23/22, 5/5/22, 5/14/22, 5/19/22 – No birds flushed.
AMCO – American coot, **AMCR** – American crow, **AMRO** – American robin, **AMWI** – American whimbrel, **BARS** – Barn swallow, **BHCO** – Brown-headed cowbird, **BLOY** – Black oystercatcher, **BLPH** – Black phoebe, **BRAC** – Brand's cormorant, **BRAN** – Brant, **BRBL** – Brewer's blackbird, **BRPE** – Brown pelican, **CAGU** – California Gull, **CCGO** – Canada goose, **CLSW** – Cliff swallow, **CORA** – Common raven, **GBHE** – Great blue heron, **GREG** – Great egret, **GRHE** – Green heron, **KILL** – Killdeer, **MALL** – Mallard, **NOHA** – Northern harrier, **NOMO** – Northern mockingbird, **PECO** – Pelagic cormorant, **PIGU** – Pigeon guillemot, **RNPH** – Red-necked phalarope, **RSHA** – Red-shouldered hawk, **RWBL** – Red-winged blackbird, **SAND** – Sanderling, **SAPH** – Say's phoebe, **SNEG** – Snowy Egret, **SOSP** – Song sparrow, **TUVU** – Turkey vulture, **WEGU** – Western gull, **WESA** – Western sandpiper

Appendix 3 (cont.). Avian Wildlife Impact Data, July 1, 2021 – December 31, 2021

Tour Date	Day	Species Present	Species Flushed
7/1/21*	Thursday	-	-
7/11/21*	Sunday	-	-
7/15/21*	Thursday	-	-
7/25/21*	Sunday	-	-
8/5/21*	Thursday	-	-
8/8/21*	Sunday	-	-
8/19/21*	Thursday	-	-
8/22/21*	Sunday	-	-
9/2/21*	Thursday	-	-
9/12/21*	Sunday	-	-
9/16/21*	Thursday	-	-
9/26/21*	Sunday	-	-
10/7/21*	Thursday	-	-
10/10/21*	Sunday	-	-
11/4/21*	Thursday	-	-
11/14/21*	Sunday	-	-
12/2/21*	Thursday	-	-
12/5/21*	Sunday	-	-
2021 TOTAL	-	-	-

*7/1/21 – 12/5/21 – Canceled due to COVID-19 impacts. No biological data collected.

Appendix 3 (cont.). Avian Wildlife Impact Data, January 1, 2021 – June 30, 2021

Tour Date	Day	Species Present	Species Flushed
1/7/21*	Thursday	-	-
1/10/21*	Sunday	-	-
2/4/21*	Thursday	-	-
2/14/21*	Sunday	-	-
3/4/21*	Thursday	-	-
3/14/21*	Sunday	-	-
3/18/21*	Thursday	-	-
3/28/21*	Sunday	-	-
4/1/21*	Thursday	-	-
4/11/21*	Sunday	-	-
4/15/21*	Thursday	-	-
4/25/21*	Sunday	-	-
5/6/21*	Thursday	-	-
5/9/21*	Sunday	-	-
5/20/21*	Thursday	-	-
5/23/21*	Sunday	-	-
6/3/21*	Thursday	-	-
6/13/21*	Sunday	-	-
6/17/21*	Thursday	-	-
6/27/21*	Sunday	-	-

*1/4/21 - 6/27/21 – Canceled due to COVID-19 impacts. No biological data collected.

Appendix 3 (cont.). Avian Wildlife Impact Data, July 1, 2020 – December 31, 2020

Tour Date	Day	Species Present	Species Flushed
7/2/20*	Thursday	-	-
7/12/20*	Sunday	-	-
7/16/20*	Thursday	-	-
7/26/20*	Sunday	-	-
8/6/20*	Thursday	-	-
8/9/20*	Sunday	-	-
8/20/20*	Thursday	-	-
8/23/20*	Sunday	-	-
9/3/20*	Thursday	-	-
9/13/20*	Sunday	-	-
9/17/20*	Thursday	-	-
9/27/20*	Sunday	-	-
10/1/20*	Thursday	-	-
10/11/20*	Sunday	-	-
11/5/20*	Thursday	-	-
11/8/20*	Sunday	-	-
12/3/20*	Thursday	-	-
12/6/20*	Sunday	-	-
2020 TOTAL	**-**	**-**	**-**

*7/2/20 - 12/6/20 – Canceled due to COVID-19 impacts. No biological data collected.

Appendix 3 (cont.). Avian Wildlife Impact Data, January 1, 2020 – June 30, 2020

Tour Date	Day	Species Present	Species Flushed
1/2/20	Thursday	AMCO, AUWA, BLPH, BRCO, GCSP, MALL, NOHA, PIGU, SAPH, WEGU	BLPH, AUWA
1/12/20*	Sunday	AMCO, BLPH, BRCO, CAGO, COHA, GREG, MALL, PECO, SAPH, SNEG, WEGU	-
2/6/20	Thursday	BRCO, SNEG, WEGU	SNEG
2/9/20*	Sunday	BRCO, GREG, WEGU	-
3/5/20	Thursday	CAGO, GREG, MALL, PECO	MALL
3/8/20	Sunday	AMCO, BRCO, CAGO, CITE, MALL, SNEG, WHIM	BRCO, CITE, MALL, SNEG
3/19/20**	Thursday	-	-
3/22/20**	Sunday	-	-
4/2/20**	Thursday	-	-
4/5/20**	Sunday	-	-
4/16/20**	Thursday	-	-
4/26/20**	Sunday	-	-
5/7/20**	Thursday	-	-
5/10/20**	Sunday	-	-
5/21/20**	Thursday	-	-
5/24/20**	Sunday	-	-
6/4/20**	Thursday	-	-
6/14/20**	Sunday	-	-

* 1/12/20 and 2/9/20 - No birds flushed.

**3/19/20 - 6/28/20 – Tours canceled due to COVID-19 impacts. No biological data collected.

AMCO – American coot, **AMCR** – American crow, **AMRO** – American robin, **AMWI** – American whimbrel, **BARS** – Barn swallow, **BHCO** – Brown-headed cowbird, **BLOY** – Black oystercatcher, **BLPH** – Black phoebe, **BRAC** – Brand's cormorant, **BRAN** – Brant, **BRBL** – Brewer's blackbird, **BRPE** – Brown pelican, **CAGU** – California Gull, **CCGO** – Canada goose, **CLSW** – Cliff swallow, **CORA** – Common raven, **GBHE** – Great blue heron, **GREG** – Great egret, **GRHE** – Green heron, **KILL** – Killdeer, **MALL** – Mallard, **NOHA** – Northern harrier, **NOMO** – Northern mockingbird, **PECO** – Pelagic cormorant, **PIGU** – Pigeon guillemot, **RNPH** – Red-necked phalarope, **RSHA** – Red-shouldered hawk, **RWBL** – Red-winged blackbird, **SAND** – Sanderling, **SAPH** – Say's phoebe, **SNEG** – Snowy Egret, **SOSP** – Song sparrow, **TUVU** – Turkey vulture, **WEGU** – Western gull, **WESA** – Western sandpiper

Appendix 3 (cont.). Avian Wildlife Impact Data, April 14, 2019 – June 30, 2019

Tour Date	Day	Species Present	Species Flushed
4/14/19	Sunday	AMCO, BLOY, BRAC, CCGO, GREG, MALL, SNEG, WEGU	BLOY, CCGO, MALL
4/18/19	Thursday	BLOY, BRAC, MALL, SNEG, SOSP, WEGU	BLOY, MALL, SNEG
5/2/19	Thursday	CCGO, BRBL, GREG, KILL, MALL, RSHA, WEGU	BRBL, CAGO, GREG, MALL, WEGU
5/5/19*	Sunday	No tour	No tour
5/12/19	Sunday	MALL, NOMO RNPH, WEGU, WESA	WESA
5/16/19	Thursday	BLPH, BRAC, GREG, KILL, MALL, RNPH, WEGU	MALL
6/2/19	Sunday	BARS, BLPH, MALL, PIGU, WEGU, WESA	BLPH, MALL WESA
6/6/19	Thursday	AMRO, BARS, BLPH, BRAC, BRBL, CAGO, CLSW, GREG, MALL, PECO, PIGU, WEGU	CAGO, GREG, PIGU, WEGU
6/9/19	Sunday	BARS, BLPH, BRAC, KILL, PIGU, RWBL, SOSP, WEGU	BARS, BLPH, PIGU, RWBB
6/20/19	Thursday	AMCR, BARS, BLPH, BRAC, PIGU, WEGU	BLPH, PIGU, WEGU

*5/5/19 - No tour; no participants

AMCO – American coot, **AMCR** – American crow, **AMRO** – American robin, **AMWI** – American whimbrel, **BARS** – Barn swallow, **BHCO** – Brown-headed cowbird, **BLOY** – Black oystercatcher, **BLPH** – Black phoebe, **BRAC** – Brand's cormorant, **BRAN** – Brant, **BRBL** – Brewer's blackbird, **BRPE** – Brown pelican, **CAGU** – California Gull, **CCGO** – Canada goose, **CLSW** – Cliff swallow, **CORA** – Common raven, **GBHE** – Great blue heron, **GREG** – Great egret, **GRHE** – Green heron, **KILL** – Killdeer, **MALL** – Mallard, **NOHA** – Northern harrier, **NOMO** – Northern mockingbird, **PECO** – Pelagic cormorant, **PIGU** – Pigeon guillemot, **RNPH** – Red-necked phalarope, **RSHA** – Red-shouldered hawk, **RWBL** – Red-winged blackbird, **SAND** – Sanderling, **SAPH** – Say's phoebe, **SNEG** – Snowy Egret, **SOSP** – Song sparrow, **TUVU** – Turkey vulture, **WEGU** – Western gull, **WESA** – Western sandpiper

Appendix 3 (cont.). Avian Wildlife Impact Data, July 1, 2019 – December 31, 2019

Tour Date	Day	Species Present	Species Flushed
7/7/19	Sunday	BARS, BHCO, BRPE, GREG, WEGU	GREG, WEGU
7/11/19	Thursday	CAGU, CORA, NOHA, PECO, PIGU, WEGU	PECO
7/14/19	Thursday	AMCR, CAGU, PECO, WEGU	WEGU
7/18/19	Thursday	AMCO, BARS, CLSW, WEGU	WEGU
8/1/19	Thursday	CORA, MALL, PECO, RNPH, SNEG	MALL, RNPH
8/4/19	Sunday	GBHE, PIGU, SNEG, WEGU	GBHE, SNEG
8/11/19	Sunday	GBHE, GREG, PECO, RNPH, SNEG, WESA	GREG, WESA
8/15/19	Thursday	BARS, GBHE, GREG, PECO, WESA	GBHE, GREG
9/1/19	Sunday	CAGU, PECO, SNEG	SNEG
9/5/19	Thursday	BLPH, GREG, PECO, SNEG, WEGU	GREG, SNEG
9/8/19	Sunday	NOHA, PECO, SAND, WEGU, WHIM	NOHA
9/19/19	Thursday	GREG, GRHE, PECO, RNPH, RTHA, SAND, WEGU	GRHE, PECO, RTHA
10/3/19	Thursday	BLPH, BRPE, CAGU, KILL, PECO, SAPH, SNEG, WHIM	BLPH, CAGU, SAPH, SNEG
10/13/19	Sunday	BLPH, NOHA, PECO, SOSH, WEGU	NOHA
11/7/19	Thursday	AMWI, BLPH, BRAN, PECO, RTHA, SAPH, WEGU	BLPH, RTHA
11/10/19*	Sunday	CLSW, PECO, TUVU	-
12/1/19**	Sunday	-	-
12/9/19	Thursday	AMWI, BLPH, BRPE, PECO, SNEG, WEGU	BLPH

* 11/10/19 – No birds flushed.
*12/1/19 – No biological data collected.

AMCO – American coot, **AMCR** – American crow, **AMRO** – American robin, **AMWI** – American whimbrel, **BARS** – Barn swallow, **BHCO** – Brown-headed cowbird, **BLOY** – Black oystercatcher, **BLPH** – Black phoebe, **BRAC** – Brand's cormorant, **BRAN** – Brant, **BRBL** – Brewer's blackbird, **BRPE** – Brown pelican, **CAGU** – California Gull, **CCGO** – Canada goose, **CLSW** – Cliff swallow, **CORA** – Common raven, **GBHE** – Great blue heron, **GREG** – Great egret, **GRHE** – Green heron, **KILL** – Killdeer, **MALL** – Mallard, **NOHA** – Northern harrier, **NOMO** – Northern mockingbird, **PECO** – Pelagic cormorant, **PIGU** – Pigeon guillemot, **RNPH** – Red-necked phalarope, **RSHA** – Red-shouldered hawk, **RWBL** – Red-winged blackbird, **SAND** – Sanderling, **SAPH** – Say's phoebe, **SNEG** – Snowy Egret, **SOSP** – Song sparrow, **TUVU** – Turkey vulture, **WEGU** – Western gull, **WESA** – Western sandpiper

Appendix 6. Publications

Trends in
Ecology & Evolution

CellPress

Review

Overcoming biotic homogenization in ecological restoration

Karen D. Holl [1,3,*,@] Justin C. Luong [1,4,@] and Pedro H.S. Brancalion [2,5]

Extensive evidence shows that regional (gamma) diversity is often lower across restored landscapes than in reference landscapes, in part due to common restoration practices that favor widespread species through selection of easily-grown species with high survival and propagation practices that reduce genetic diversity. We discuss approaches to counteract biotic homogenization, such as reintroducing species that are adapted to localized habitat conditions and are unlikely to colonize naturally; periodically reintroducing propagules from remnant populations to increase genetic diversity; and reintroducing higher trophic level fauna to restore interaction networks and processes that promote habitat heterogeneity. Several policy changes would also increase regional diversity; these include regional coordination amongst restoration groups, financial incentives to organizations producing conservation-valued species, and experimental designations for rare species introductions.

Highlights

Anthropogenic activities are leading to biotic homogenization.

Common ecological restoration practices often contribute, rather than counteract biotic homogenization at the species, functional, and phylogenetic levels.

It is important to think critically about how to integrate individual restoration projects to most effectively conserve regional biodiversity.

We offer several recommendations to improve restoration practices and policies to increase gamma-diversity in order to maintain ecosystem resilience in a changing world.

Biotic homogenization in restored landscapes

Extensive evidence shows that anthropogenic activities are leading to **biotic homogenization** (see Glossary). Namely, lower **alpha-diversity** (within-site) and **beta-diversity** (increased compositional **similarity** across sites) have led to a reduction in **gamma-diversity** (regional) over time (e.g., [1–4]). In general, anthropogenic impacts such as climate change, fragmentation, and altered disturbance regimes create abiotic and biotic filters that select for overlapping and similar traits that lead to biological simplification [5–7]. The 'winner' species comprise both widespread, native generalists and invasive, non-native species that readily disperse and grow rapidly; are commensal with humans; and thrive in disturbed environments [1,8,9]. These species outcompete and often have complex trophic effects on more specialized, endemic, and rarer native species [10,11]. Hence, biotic homogenization has clear implications for both biodiversity conservation and human wellbeing, since 'loser' species may play critical roles for provisioning ecosystem services [9]. Ultimately, this homogenization process will likely compromise landscape functionality and undermine the potential of both ecosystems and humans to thrive in a changing environment.

Ecological restoration has been suggested as a strategy to increase biological diversity and overcome the trend towards biotic homogenization at the landscape scale [12,13]. Although there has been extensive debate about the endpoint of restoration efforts in a rapidly changing climate and recognition that restorative activities are undertaken with a wide variety of goals, many restoration projects are motivated by the broad intention of 'reconstructing' [14] or 'rewilding' [15,16] native ecosystems to recreate the processes, functions, structure, and composition of a native reference system. If restoration practices reintroduce a genetically and compositionally diverse suite of species, including those that are rare and at risk of extinction, this could transform restoration into a powerful tool to reverse biotic homogenization in human-modified landscapes [17]. However, most restoration projects set objectives based on overall cover or abundance of native species and within-site species richness (alpha-diversity) [18,19],

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rather than considering compositional similarity across sites (beta-diversity) and whether the full suite of regional species (gamma-diversity) is re-establishing.

Here we demonstrate that, despite good intentions, ecological restoration efforts often contribute to, rather than counteract, biotic homogenization and discuss the reasons that lead to this trend. We propose strategies to encourage the restoration of broader taxonomic, functional, and genetic diversity across restored sites in the context of regional landscape, including both restored and remnant sites. It is important to think critically beyond individual restoration projects to the broader issue of regional conservation as we embark on the UN Decade on Ecosystem Restoration and restored sites become an increasing portion of human-dominated landscapes. At the same time, we recognize the tradeoffs between increasing gamma-diversity, meeting multiple stakeholder goals, and maximizing the area restored with limited funding.

The evidence

Numerous studies from throughout the world report that even when restoration projects succeed in achieving native species abundance and richness targets, they often are dominated by a subset of the regional species pool that naturally regenerates in or is commonly reintroduced to restored sites (Table 1). For instance, Sapkota *et al*. [20] found that stem-density of woody plants was similar in restored and reference forest stands in Nepal, but beta- and gamma-diversity were higher in reference forests due to the dominance of a single planted, native species (sal tree, *Shorea robusta*) across multiple restored sites. Likewise, Hayward, *et al*. [21] reported that beta-diversity was greater across unlogged dipterocarp forest in Borneo than among either naturally regenerated or actively restored post-logging sites. Conversely, rarer, less-competitive, and highly specialized species are often lacking from restored sites, as compared with nearby reference ecosystems [22–25]. There are, however, exceptions to this trend [12,26].

The species that commonly establish and proliferate in restoration sites typically have traits favored by disturbance. These include adaptations to reproduce large numbers of offspring, disperse widely, and spread asexually; to grow quickly when light, water, and nutrient resources are abundant; and to tolerate cohabiting with humans and the stressors associated with anthropogenic activities [1,8,27,28]. This results in lower diversity of **functional traits** across many restored sites as compared with reference systems [29,30]. For example, D'Astous *et al*. [31] reported that restored peatlands had a narrower range of traits related to flood tolerance and lower average seed mass than remnant sites.

Table 1. Examples[a] of different types of biotic homogenization in restored sites

Type of homogenization	Examples	Refs
Lack of rare, specialized, or endangered species	Temperate forest and grassland plants, grassland moths, wetland algae	[22–24,96]
Low gamma-diversity across restoration sites	Grassland bees and plants, multiple tropical forest taxa	[2,21,24,25] (Box 1)
Predominance of certain functional traits	Peatland plants, tropical forest dung beetles, stream invertebrates, tropical forest trees	[29–31,56]
Phylogenetic homogeneity	Tropical forest and grassland plants, tropical forest birds	[32–34]
Lack of genetic diversity	Mangrove forest, tropical forest birds, greenhouse plants	[36,37,57]
Trophic downgrading	Terrestrial and stream invertebrates, tropical forest birds	[28,44,97]

[a]These are illustrative examples of different types of biotic homogenization rather than a systematic literature review.

Glossary

Alpha-diversity: the species diversity of a relatively small area. For the purposes of this review, it refers to diversity in a single restoration project or study site.
Beta-diversity: the component of gamma-diversity that accumulates as a result of differences between sites. Includes heterogeneity resulting from stochastic variation within a single habitat and differences between habitats along environmental gradients.
Biotic homogenization: the replacement of high-diversity biotas by low diversity and more similar biotas.
Ecological restoration: the process of assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed.
Functional traits: the ecological attributes of a species that relate to dispersal, survival, capture of resources, and the effect of that species on the overall pool of resources in the ecosystem.
Gamma-diversity: the number of species found across a relatively large area. It is the product of alpha- and beta-diversity. For the purposes of this review, gamma-diversity corresponds to the diversity of a landscape or an ecoregion.
Habitat: variations of an ecosystem along abiotic gradients that support different species compositions. For example, California grassland composition differs as a function of soil type (e.g., serpentine grasslands) and soil moisture (e.g., wet meadows).
Similarity: (also compositional similarity); a metric of how much the species composition of two or more sites overlap.

Given that functional traits are often conserved phylogenetically, it is not surprising that several studies also report lower phylogenetic diversity in restored than reference sites [32,33]. Cosset and Edwards [34] found the avifaunal community in restored sites had lower phylogenetic and functional diversity than remnant sites. Turley and Brudvig [35] reported that savanna restoration in former agricultural lands in the southeastern US improved phylogenetic diversity, but not to the level in reference systems.

Likewise, a growing body of evidence suggests that restored sites often host lower genetic diversity than reference systems ([36,37] but see [38,39]), particularly of species with small populations and those that are propagated clonally [40]. This trend is consistent with a recent meta-analysis that showed that *ex situ* plant populations, which often serve as the source for vegetative material for restoration, have lower genetic diversity than wild populations; this is due both to practitioners not collecting across the full species range and to genetic erosion over time [41]. This pattern is highly concerning given that maintaining and increasing genetic variability is key to species adjusting to rapidly changing climatic conditions [42,43].

Several studies also demonstrate that restored sites tend towards trophic downgrading and simplification of species interaction networks, as a result of reduction or absence of top-level predators and species with specialized mutualisms in restored sites (Table 1). Tullos *et al*. [28] found more macroinvertebrate shredders in reference streams and a greater abundance of collector-gatherers in restored streams, indicating trophic downgrading. Likewise, trophic levels and body sizes of birds were lower in restored compared with reference montane forests in Rwanda due to the absence of raptors and large-bodied frugivores and invertivores [44].

What is less clear is whether gamma-diversity will increase or decrease over time across restored sites given the paucity of long-term, multi-site restoration studies. Classic forest succession models predict that a more diverse suite of **habitat** specialists will disperse to and establish in restored sites over time, but the few long-term, multi-site restoration studies show that this does not necessarily happen [22,45,46] (Box 1). Moreover, restoration typically occurs in fragmented habitats with strong edge effects that favor invasive species [47] and recurring anthropogenic disturbance [48], thereby leading to positive feedbacks towards homogenization. Finally, in some cases, recently restored areas may create suitable habitat for rare and threatened disturbance-dependent species in landscapes with limited early-successional habitat and thereby increase gamma-diversity [12,49].

Causes of biotic homogenization in restoration

Local and landscape context

These patterns of species, functional, and genetic homogenization in restored sites can be explained by various factors. To start, conditions both within and in the landscape surrounding restored sites favor biotic homogenization. By default, restored sites have a history of disturbance, which selects for disturbance-adapted native species and invasive, non-native species that are strong dispersers and competitors and, in turn, promotes homogenization. Moreover, restoration sites often lack the within-site abiotic heterogeneity (e.g., microtopography, soil moisture) that provides a range of niches for different species [50,51].

Restored sites are often embedded in landscapes where remnant habitats are highly fragmented and affected by anthropogenic impacts (e.g., selective logging, hunting, influx of agricultural chemicals), which results in biotic homogenization of the species pools available to colonize restored sites [2,9,52]. The abundance of generalist native and invasive non-native species in most fragmented landscapes, combined with the typically strong dispersal abilities of these species, means that they are highly likely to be the 'winners' [9,53] (Figure 1B). For example,

Box 1. Biotic homogenization in restored California coastal prairies

California coastal prairies are the most species-rich grassland type in North America, but common restoration practices typically do not aim to restore the full suite of possible species. Lesage *et al*. [55] reported that practitioners recognized the conservation value of less commonly used species but did not plant them due to risk-aversion and concerns about meeting compliance standards. Luong (J.C. Luong, Doctoral dissertation, University of California Santa Cruz, 2022) further addressed this question by measuring vegetation composition and conducting land manager surveys of 37 restored coastal prairies. The sites ranged in age from 3 to 30 years post-implementation and spanned a 1000-km north–south climate gradient in coastal California. They found that nearly 50% of practitioners plant the same four perennial grass species (Figure I), despite the fact that coastal grasslands host over 400 native species, many of which are annual forbs. Some practitioners indicated use of both widespread and less-common species if they already felt confident in achieving their project targets. Practitioners preferentially selected perennial bunchgrasses because they are competitive and easy to establish with limited resources. These results suggest that current restoration practices are leading to taxonomic biotic homogenization of coastal grasslands and a lack of recovery for regionally rarer species.

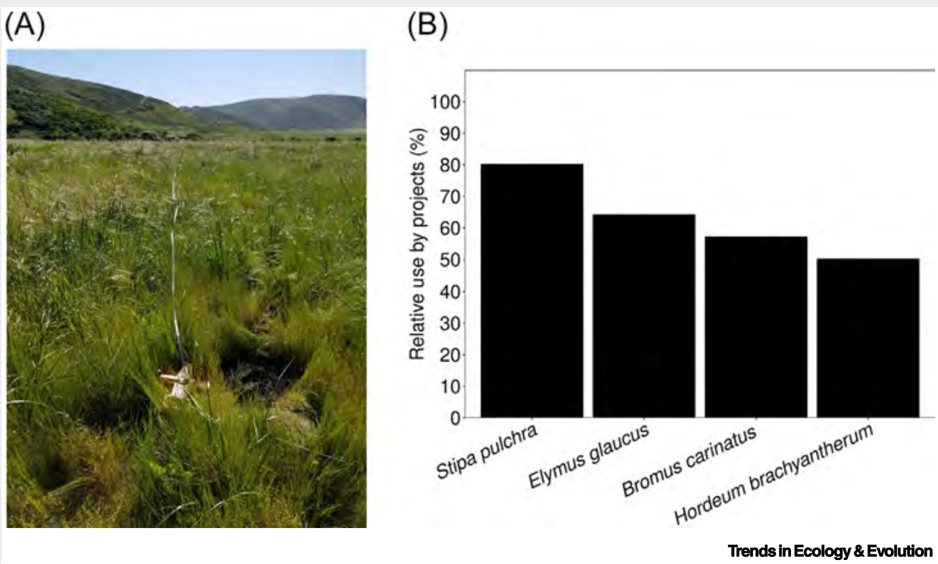
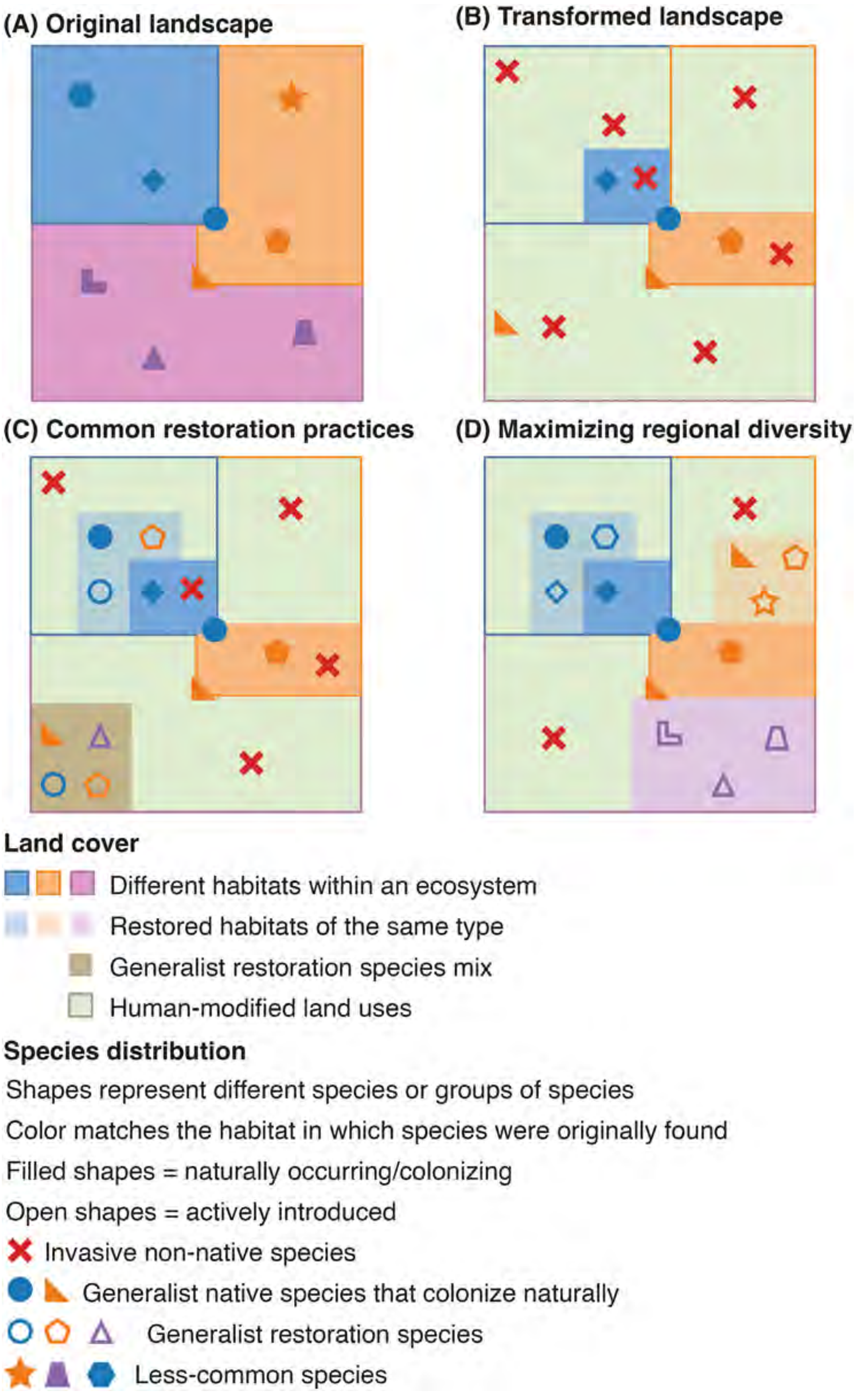


Figure I. (A) Restored coastal prairie dominated by one perennial grass, *Stipa pulchra*, a species that is commonly planted along the entire California coast. (B) Percentage of projects in which the most commonly used species were planted; practitioners preferentially selected these species because they have high survival or growth.

habitat fragmentation and defaunation in tropical forests has led to a paucity of fauna capable of dispersing large seeded, later-successional tree species [54].

Restoration actions

In addition to local and landscape conditions, some commonly employed restoration practices promote biotic homogenization. These practices stem from practical, economic, and legislative constraints. First, despite the fact that species composition varies across abiotic gradients (i.e., habitats) within an ecosystem (Figure 1A), practitioners often reintroduce the same species at multiple sites across the landscape (Figure 1C). Commonly used species typically are cheap and easy to propagate; have well-established collection, propagation, and reintroduction methods; and have a record of establishing well [55] (Figure 1C). This reduces project costs and increases the likelihood of achieving restoration objectives. In some cases, these are the same widespread native generalist species that establish naturally (Figure 1C). Luong *et al*. (Box 1) found that practitioners introduced a similar subset of perennial grass species in 37 grassland restoration projects spanning 1000 kilometers along the California coast. Moreover, the only



(See figure legend at the bottom of the next page.)

commonly reintroduced forb species is yarrow (*Achillea millefolium*), a circumboreally distributed perennial species that colonizes naturally through both seed dispersal and vegetative spread. Brancalion *et al*. [56] reported that nurseries in southeastern Brazil lacked large-seeded, later-successional trees due to the high cost of propagating these species, despite their ecological importance.

Second, restoration nurseries are under pressure to produce large quantities of seeds and plants to meet the growing demand, which encourages collecting seed and vegetative material from the largest, most productive plants at the peak time of plant maturation, which can lead to genetic homogenization [56–58]. In addition, nurseries may not be allowed to collect seeds in protected areas, often a major repository of rare, specialized species [59], and it can be challenging or impossible to collect species that are legally protected due to complicated and costly permitting procedures. As a result of the high demand for seed to scale-up restoration, plants of short-lived species are often grown in the greenhouse or on seed farms to increase the amount of seed. However, multiple cycles of farm- or greenhouse-grown seeds for restoration use can result in reduced genetic diversity and plant fitness, as compared with wild populations [57,58,60].

Finally, terrestrial restoration projects largely focus on reintroducing plants rather than fauna, fungi, and microbial communities, in part because it is challenging to reintroduce larger predatory fauna [61] and other species with complex mutualistic interactions [62]. This favors the reintroduction of generalist and lower-trophic level species, simplifies interaction networks in restored sites, and can have cascading effects on regional diversity [61,63]. For example, Walsh *et al*. [64] assert that it would be extremely challenging to restore the endangered Hawaiian succulent lobelia (vulcan palm, *Brighamia insignis*) due to lack of visitation by specialized hawkmoth pollinators.

The tendency towards using easy and tried-and-true species is understandable given the need for practitioners to meet restoration targets, particularly for projects that are legally mandated and do not receive financial incentives to cover the additional costs involved in the production of conservation-valued species. For example, Lesage *et al*. [55] found that, due to both cost and risk aversion, grassland restoration practitioners in California preferentially used competitive perennial species, rather than including the annual forb species that comprise a large proportion of California grassland plant diversity. Annual plant populations fluctuate dramatically from year to year, making it challenging for practitioners to achieve restoration targets when using annual species. In addition, using harder to propagate and slower growing species will likely reduce survival and delay the structural recovery of the ecosystem, which may increase maintenance costs. Reintroducing vertebrate fauna can be extremely expensive, require large areas, and be socially controversial [65].

Recommendations to improve gamma-diversity

Proactive planning is essential for restoration efforts to succeed in the promise of counteracting biotic homogenization and restoring all aspects of biological diversity across the landscape. We suggest a number of restoration practices and policies that will help to achieve this end

Figure 1. Counteracting biotic homogenization of plants in restored landscapes.

For a Figure360 author presentation of Figure 1, see https://doi.org/10.1016/j.tree.2022.05.002.

(A) Original landscape in which habitats with different species compositions are distributed across abiotic gradients (e.g., moisture, soil type) within an ecosystem type (e.g., coastal grassland, tropical forest). (B) Landscape transformed by land conversion to anthropogenic uses (e.g., agriculture) results in habitat fragmentation, biotic homogenization, and the spread of invasive, non-native species and generalist, native species. (C) Common restoration practices in which a similar, generalist restoration species mix is planted throughout the landscape. (D) Restoration aimed at maximizing gamma-diversity by prioritizing locations that enhance connectivity (restored habitats adjacent to remnants), matching species compositions to the original abiotic conditions, planting less-common species that rarely colonize naturally, and making more extensive efforts to control invasive species in restored habitat.

(Box 2). We acknowledge that many of these practices will increase the costs of restoration and, as such, will require careful consideration of trade-offs between maximizing the area restored versus the regional biodiversity conserved.

First, restoration sites that are located near or facilitate connectivity with source populations of flora and fauna should be prioritized to maximize both the taxonomic and genetic diversity of colonizing species, minimize edge effects, and enhance connectivity with hydrologic processes [37,66–68] (Figure 1D). The development and application of novel remote-sensing and analytical techniques have greatly enhanced the capacity to select sites that maximize connectivity and to monitor the restoration of biodiversity at large spatial scales [69,70]. Of course, the feasibility of maximizing connectivity depends on the extent and quality of remnant habitat in the landscape, as well as land ownership and the amount of fungibility amongst potential restoration sites.

Second, restoration should be designed to provide sufficient habitat heterogeneity both within and among sites to provide niches for a range of species. This is done most effectively by restoring the

Box 2. Recommendations for overcoming biotic homogenization in restoration

Site selection and protection

- Prioritize restoration sites near diverse source populations to maximize landscape connectivity
- Favor areas that maximize environmental heterogeneity and thus habitat variability for a diverse suite of native plant and animal species
- Use spatial analysis tools and both field-collected and remotely-sensed data to select sites and map environmental variability
- Protect restoration sites against reconversion to allow time for a diverse suite of species to colonize and establish

Species selection and propagation

- Select species for reintroduction that:
  - are unlikely to colonize naturally
  - are adapted to localized abiotic habitat conditions rather than using primarily widespread, generalist species
  - represent phylogenetic and trait diversity
  - facilitate the colonization of and interactions with other species
- Follow existing guidelines for propagule collection that maximize genetic diversity
- Periodically introduce individuals from wild-collected populations to supplement the genetic diversity of greenhouse- or farm-grown plants and captively-bred fauna
- Improve information sharing about propagation, captive breeding, reintroduction, and maintenance methods, particularly in widely accessible online formats
- Create programs to exchange genetic material amongst organizations (e.g., nurseries, zoos), thereby maximizing diversity without each organization having to collect all species or as many individuals of a single species

Restoration interventions

- Restore historic abiotic heterogeneity within habitats
- Re-establish historic disturbance regimes that create habitat heterogeneity
- Control invasive species and in some cases widespread, generalist native species that inhibit the establishment of a diversity of native species
- Reintroduce later-successional species after habitat conditions are more suitable
- Consider the mosaic of resources and habitat features that are required for faunal movement, foraging, and reproduction
- Increase reintroductions of fauna to restore species interaction networks

Policies

- Coordinate restoration species selection regionally across different land management organizations to maximize gamma-diversity
- Include requirements for the use of some less-common species in restoration regulations
- Provide financial incentives to groups producing and reintroducing conservation-valued species
- Include species composition measurements as part of restoration monitoring frameworks
- Budget sufficient funding for long-term monitoring and adaptive management
- Allow experimental designations to allow for trial introductions of rarer species
- Provide access to sources of propagules of rare and specialized species

natural processes and disturbance regimes (e.g., channel meandering, fire, large ungulate grazing) that create heterogeneous habitat conditions [16]. In cases where this is not possible, it may be necessary to actively restore small-scale topographic heterogeneity to concentrate nutrient and water resources [50]. The plant species reintroduced should be tailored to localized habitat conditions (Box 2, Figure 1D). Restoring habitat heterogeneity for fauna requires specific consideration of the mosaic of habitat types and resources needed for movement, foraging, reproduction, and protection from predators, rather than assuming all restored habitat is equally suitable [63,71].

Third, the suite of species actively introduced to a site must be thoughtfully selected and coordinated regionally (Box 2). We recommend selecting species with a range of traits and phylogenetic diversity, that are adapted to the local habitat conditions, and that will facilitate the colonization of and interactions with other species [15,72–74]. For example, fleshy-fruited tree species serve to attract seed-dispersing birds for tropical forest restoration [75]. Likewise, reintroducing faunal species can restore ecological processes and habitat heterogeneity. For example, reintroduction of the giant Galapagos tortoise (*Chelonoidis hoodensis*) has reinitiated seed dispersal and increased the recruitment of juvenile plants of the endangered tree cactus, *Opuntia megasperma* var. *megasperma* [76]. Whereas many restoration projects primarily reintroduce early-successional, disturbance-adapted plant species, more effort should be focused on reintroducing those species that are less likely to colonize naturally (Figure 1D) and ideally introducing them later in restoration once site conditions are more favorable for their establishment [77,78].

Diversifying the suite of actively reintroduced plant and animal species will require further research on how to propagate and reintroduce less common species and potentially financial incentives to those that produce them, particularly in highly diverse systems [56]. Equally important is improving the sharing of this information, which is often passed on verbally through informal communications amongst restoration practitioners. Recently, some online, open access portals have been developed to share information more broadly about plant selection and propagation, which can serve as models (e.g., [79], see Table 3 in [80], http://data.kew.org/sid/]. For example, the Diversity for Restoration free online tool was originally developed for tropical dry forest trees of Colombia and is being expanded to other countries; the tool combines habitat suitability maps now and under future climate conditions, functional trait and phylogenetic information, and local ecological knowledge to guide selection of species and seed sources tailored to habitat conditions and project goals [80]. In addition, trait data for many plant species are available on the TRY database (https://www.try-db.org/TryWeb/Home.php), facilitating their incorporation in plant species selection.

Fourth, recent studies show that restoration efforts can be successful in improving genetic diversity when pursued with intentionality [60,81]. This requires following existing, best-practices guidelines for collecting plant materials, such as collecting from a minimum number of individuals and populations, across the temporal and spatial range of where species reproduce, and from both small and large individuals, as well as keeping detailed records of where and when the seeds were collected [60,82,83]. It is also important to continue to collect from wild populations over time to maintain genetic diversity, following best practices to minimize impacts on the source populations, rather than solely relying on seed farms or captively bred faunal populations [58,59]. Initiatives such as the Ecological Restoration Alliance of Botanic Gardens [84] contribute to coordinating the supply of conservation-valued species to restoration projects and trading seeds amongst groups to increase genetic diversity among *ex situ* collections.

Fifth, restoration projects must be protected and maintained for the long-term to allow for the colonization and establishment of suitable habitat for a diverse suite of species over time. The specific ongoing maintenance activities needed will depend on the ecosystem and site conditions. Reintroducing rarer and later-successional species once suitable habitat conditions have developed is more successful in some ecosystems [85,86], but is challenging given the short timeline of many restoration projects. In ecosystems that have evolved with specific natural disturbances and host a diversity of disturbance-dependent species (e.g., chaparral: fire; riparian forests: flooding), maintaining a disturbance regime and mosaic of habitat stages will be key to maximizing gamma-diversity. In many ecosystems, ongoing invasive species removal will be necessary to maintain and enhance gamma-diversity.

Implementing these recommendations will require modifying restoration targets, financing, and regulations. Most restoration compliance targets focus on cover, abundance, or alpha-diversity, rather than regional-scale diversity. These site level requirements are necessary, but should be complemented with regional coordination of restoration efforts to maximize gamma-diversity at a landscape scale. For example, the Atlantic Forest Pact, a group of over 270 business, government, academic, and non-profit groups that aims to restore 15 million hectares of Brazilian Atlantic forest, has worked together to coordinate research efforts and share information that have supported the propagation of over 150 tree species within individual forest nurseries [87] (Box 3). Projects that include restoration of rarer species and habitats could be prioritized for funding from public sources, such as the US Wetland Reserve Program (now part of the Agricultural Conservation Easement Program: https://www.landcan.org/local-resources/Agricultural-Conservation-Easement-Program-ACEP/35602) which provides a 50–75% cost-share to farmers and ranchers who restore wetlands on their land. Likewise, increasing gamma-diversity might be part of countrywide restoration policies, such as the recently issued Chinese National Guidelines for restoration [88] and other similar efforts that are underway as part of the UN Decade on Ecosystem Restoration. Additionally, policies for compliance projects, especially those driven by biodiversity offsetting policies, should require that projects incorporate at least a few native species that are part of the regional species pool but not commonly used in restoration. Quite often, such policies focus on a narrow suite of biodiversity and fail to minimally compensate for the destruction of native ecosystems [89].

To alleviate restoration practitioners' concerns about using poorly tested species, regulations should include research designations to allow for testing new methods and species. For example, under the US Endangered Species Act, reintroduced populations can be designated as 'experimental' to allow for research on how to most successfully establish and grow species without increasing landowner liability. In addition, regulations should allow seed collectors to responsibly access rare and legally protected species and botanical gardens to establish seed orchards with these species.

Concluding remarks

The UN Decade on Ecosystem Restoration and other related initiatives have lofty goals for restoring biodiversity and associated ecosystem services and improving human livelihoods. Achieving these goals, however, will not be easy. Realizing the full potential of restoration to counteract biotic homogenization will require additional research on strategies to increase the recovery of gamma-diversity, as well as longer-term, multi-site studies to compare the outcomes of such efforts over time (see Outstanding questions). Indeed, mimicking the complex and long-term processes of species assembly comprises a major scientific challenge [90]. Moreover, we need to work toward feasible and effective policies to restore gamma-diversity and further promote regional collaboration, rather than competition, among restoration initiatives operating in the same landscape.

Equally, if not more difficult, will be evaluating critical trade-offs between maximizing the area restored; meeting the needs of local stakeholders, and the additional costs, labor, and time needed to undertake actions to enhance regional biodiversity; and identifying synergies to meet

Outstanding questions

How much does gamma-diversity recover naturally over time?

Does investing additional resources in active restoration increase gamma-diversity beyond simply allowing for natural regeneration?

To what extent will measures to reverse biotic homogenization be undermined by environmental changes?

What are the best strategies to restore the pre-disturbance habitat heterogeneity needed to provide appropriate conditions for the full suite of species?

How do we restore rare species with complex species interactions and maintain them over the long-term?

Does implementing measures to reverse biotic homogenization compromise other restoration goals, such as carbon sequestration, soil protection, and improving human livelihoods?

What is the balance between the increased restoration costs, including long-term maintenance and adaptive management, to increase gamma-diversity and the potential financial benefits resulting from it (e.g., carbon sequestration, pollination, ecotourism)?

Where does one draw the line in how many rarer species to include while balancing restoration budgets?

What policy regulations or incentives are most effective for increasing regional gamma-diversity?

How do we most effectively coordinate species selection for restoration across ecoregions?

Box 3. Increasing gamma-diversity in restoration of the Brazilian Atlantic forest

The Atlantic forest of Brazil is one of the most biodiverse ecoregions of the world with 3263 tree species, of which ~60% are endemic. Restoring such a huge diversity of trees is a major challenge for forest restoration programs and a valuable opportunity to save hundreds of species from extinction. Restoration programs in this region have made use of a relatively high diversity of tree species (Figure I), but the restoration species' pool is composed mostly of a narrow group of species with similar traits. In a large-scale assessment of tree diversity in restoration plantations in the Atlantic Forest, based on 961 restoration projects and more than 14 million seedlings planted, Brancalion *et al*. [56] found that species composition was highly biased towards small-seeded, wind-dispersed, and cheaper seeds. To counteract this under-representation of tree species diversity in restoration programs, several strategies have been established: (i) seed exchange programs among nurseries have been organized, thereby maximizing genetic and species diversity [93]; (ii) legal policies now require a minimum number of native tree species in restoration programs [94]; (iii) capacity-building courses have been organized with seed collectors and local communities [87]; and (iv) spatial prioritization analyses have been used to select areas with greater potential to mitigate species extinctions [69] and maximize landscape connectivity [95], which may promote the arrival of rare and threatened species in restoration sites.

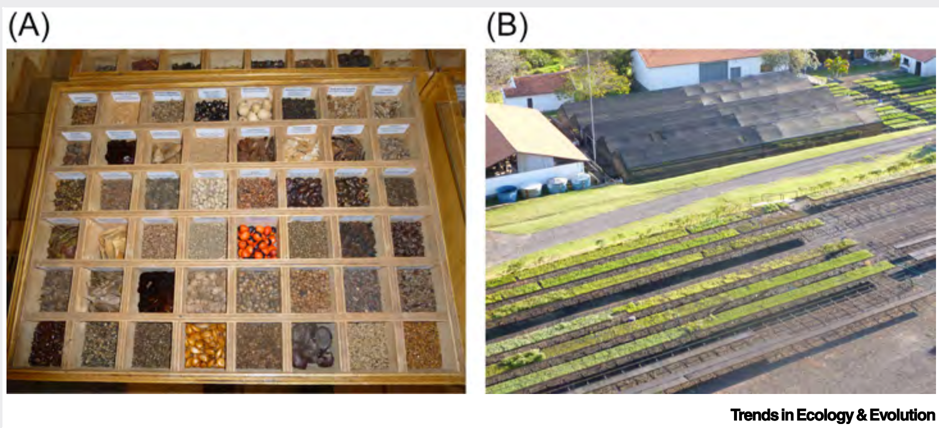


Figure I. (A) Collection of various Atlantic forest tree seeds used for restoration. (B) Large nursery with the capacity to produce ~1 million seedlings annually of a diversity of native species.

multiple goals. A key step in all restoration projects is clearly identifying and agreeing to goals amongst stakeholders so that appropriate methods can be selected [91]. For example, if projects are driven by biodiversity offsets then maximizing biodiversity should be a priority, whereas if forest landscape restoration projects are focused on providing income and food sources to local landholders, introducing a smaller suite of economically and culturally valuable tree species may be a more appropriate strategy. Fortunately, some examples, such as a large-scale forest corridor restoration project in the Pontal do Paranapanema region of Brazil, demonstrate that with careful planning, regional biodiversity, habitat connectivity, and local stakeholder livelihoods can be simultaneously improved [92] (Box 3), though this will not be the case for all projects.

Nonetheless, restoring gamma-diversity is critical to maintaining functioning ecosystems that are resilient to climate change and, ultimately, to achieving most of the benefits that motivate ongoing restoration initiatives. We highlighted causes of biotic homogenization in ecological restoration and recommended potential strategies to overcome them (Box 2). A thoughtful consideration of these mechanisms and application of solutions is now needed as part of an integrated effort among restoration organizations, practitioners, researchers, and policymakers.

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Declarations of interest

No interests are declared.

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RESEARCH ARTICLE

Nonperiodic grassland restoration management can promote native woody shrub encroachment

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Woody species encroachment is increasingly displacing grasslands, negatively impacting regional plant richness and reducing economic productivity from grazing. Although intermediate disturbance has been found to reduce woody species encroachment and maximize species diversity, ecological restoration can often lead to many small, infrequent disturbances. These small disturbances may not be strong enough to limit woody encroachment, and instead may promote invasion. Drought may slow encroachment, but adjustments in key functional traits may allow for persistent woody invasion. *Baccharis pilularis* is a woody shrub native to western North America, but has been shown to have higher recruitment following nonperiodic disturbances and be invasive in native grasslands. To address the extent of woody invasion following limited restoration actions, I quantified natural *B. pilularis* recruitment and cover at an invaded coastal California grassland in plots after experimental restoration (singular planting and nonnative species control efforts) and extreme drought conditions (60% rain exclusion) 6 years posttreatment. For traits, I measured *B. pilularis* specific leaf area, major vein length per unit area, leaf thickness, and lobedness 4 years posttreatment and stem diameter 5 years posttreatment. Native shrub encroachment by *B. pilularis* was higher in restored plots compared to nonrestored plots, which had zero recruitment. Drought reduced *B. pilularis* recruitment but not cover and resulted in adjustments in leaf thickness and major vein length per area. Results suggest that planting and other singular restoration activities (i.e. invasive species control) in coastal grasslands can cause small, infrequent disturbances that promote native woody shrub encroachment.

Key words: ***Baccharis pilularis*, drought-net, intermediate disturbance hypothesis, manual restoration, restoration disturbance, woody species invasion**

Implications for Practice

- Infrequent restoration activities such as singular planting or weeding efforts can create small disturbances that facilitate woody invasion by *Baccharis pilularis*.
- Establishment of periodic disturbance regimes may prevent woody encroachment of restored California grasslands to shrub and woodlands if the underlying management goal is to preserve grassland habitats.
- Restoration of drier microhabitats may limit woody recruitment, but management may still be needed to prevent woody invasion because the invading *B. pilularis* population that establishes, achieves similar cover to the invading population not experiencing drought.

Introduction

Globally, native woody species can become invasive and encroach into historic grasslands (McBride & Heady 1968; Ghersa et al. 2002; Stevens et al. 2017). Woody encroachment has accelerated in past years due to altered disturbance regimes and increased atmospheric nitrogen deposition (Van Auken 2009), but is an increasing management concern (Archer & Predick 2014; Fogarty et al. 2020) because it locally displaces grassland habitats with high conservation values (Ford & Hayes 2007; Stevens et al. 2017). Loss of grassland habitat reduces economic returns from grazing (Zarovali et al. 2007; Anadón et al. 2014) and decreases regional plant species richness (Van Auken 2009; Ratajczak et al. 2012) which can negatively impact higher tropic levels that rely on diverse plant hosts (Coppedge et al. 2001; Beal-Neves et al. 2020).

Woody species are better able to establish during wet periods (Williams et al. 1987; Archer 1990; Browning et al. 2008) and can persist into drier years if their taproots grow deep enough (Van Auken 2009). Until recently, habitat conversion of grasslands into shrublands or woodlands were often prevented by historic disturbance regimes (Van Auken 2009; Stevens

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et al. 2017). Historic disturbance regimes were typically implemented by indigenous tribes through prescribed burns (Anderson 2007) and can limit woody invasion (DeSantis et al. 2011). Many grasslands were also previously grazed by now-extirpated or extinct ungulates which also helped to abate woody shrub invasion (Wigand 2007). As previous research has found moderate disturbance is required to maintain grasslands and maximize species diversity (Hobbs & Huenneke 1992; Peterson & Reich 2008; Mayor et al. 2012), the intermediate disturbance hypothesis (Connell 1978), may provide a fitting framework to describe grassland community dynamics. In fact, this may be the theoretical basis for grazing programs and annual mowing that historically employed by land managers and restoration practitioners in grasslands globally (Tälle et al. 2016).

Habitat type conversion occurs when a habitat surpasses a threshold that causes the system to be converted to a different ecosystem (Beisner et al. 2003). Protecting grasslands in California from habitat conversion is a strong conservation priority because they support high levels of herbaceous diversity that are not often present in temperate shrub or woodlands (Ford & Hayes 2007). For example, a survey from California grasslands found that just 13 remnant grasslands harbored more than 40% of state's total native plant diversity, along with several rare and endangered species of concern (Schiffman 2007). California native grasslands previously encompassed 25% of the state, but only 1% of native grasslands have not been strongly affected by land development or species invasions since European colonization (Jantz et al. 2007). Historic and large reductions of native grasslands indicate that restoration will be needed for future habitat recovery. However, similar to many other regions in the world, woody species encroachment has been documented to be increasing in California for nearly a century (McBride & Heady 1968; Williams et al. 1987; Laris et al. 2017).

Studies from both Texas and South Africa suggest that extended droughts may constrain and potentially reverse woody species encroachment (Twidwell et al. 2014; Case et al. 2020). In Australia, woody species encroachment was found to be slowed, but not reversed by extreme drought (Zeeman et al. 2014). More research is needed to understand how woody species and grasslands in California will respond, because it is expected that rainfall will become more spatially and temporally variable, portending longer and more extreme droughts (Swain et al. 2018). Increased temporal variability in rainfall will lead to less available water for plant use (Loik et al. 2004), and potentially slow woody species encroachment (Twidwell et al. 2014; Zeeman et al. 2014; Case et al. 2020). Functional traits may be especially useful in understanding the mechanisms that potentially halt woody invasion during drought (Cadotte et al. 2015; Luong et al. 2021). For example, wood density, which is negatively related to stem diameter (Chave et al. 2009; Markesteijn et al. 2011), can support higher drought tolerance through cavitation resistance (Hacke et al. 2001) and help explain woody encroachment during drought, while key leaf traits are often related to resource acquisition and drought tolerance (Sack & Scoffoni 2013; Cadotte et al. 2015; Pérez-Harguindeguy et al. 2016).

Ecological restoration attempts to enhance degraded ecosystems through common practices such as nonnative species removal and reintroductions (via planting and seeding) of native species (Gann et al. 2019). Planting efforts and nonnative species removal often lead to small-scale soil disturbances (D'Antonio & Meyerson 2002). Disturbed open spaces freed from nonnative species removal are often recolonized during secondary invasions of fast growing, unplanted native or nonnative species with high reproductive output (Zavaleta et al. 2001; Pearson et al. 2016). Although intermediate disturbance such as periodic burning, grazing, or mowing may serve to improve species richness in restored grasslands (Connell 1978; Hobbs & Huenneke 1992), restoration often focuses limited resources solely on the removal of the most noxious nonnative species and ignore most other plants (Holl & Howarth 2000; Pearson et al. 2016). Newly bared ground may effectively provide open habitat for fast-growing shrubs to invade during ideal years (Tyler et al. 2007; Pierce et al. 2017). A common native woody invader in California, *Baccharis pilularis* DC., was previously found to establish better when nearby nonnative annual grasses were removed (da Silva & Bartolome 1984) and found to frequently encroach into California coastal grasslands (McBride & Heady 1968).

Reestablishing historic disturbance regimes is another growing restoration practice, but past evidence indicates that temporally limited restoration actions can promote native and nonnative woody invasion in open grassland habitat (Hobbs & Mooney 1985; Laris et al. 2017; Abella et al. 2020; Hopkinson et al. 2020). Abella et al. (2020) and Hopkinson et al. (2020) both found that singular prescribed fires without additional maintenance promoted woody invasion. In pampa grasslands, researchers found that singular small- and large-scale experimental disturbances led to increased recruitment of woody tree species in mesic conditions, but not consistently for drier plots (Mazía et al. 2019). Peltzer and Wilson (2006) found that extreme weather events could also result in disturbances that promotes woody species invasion. Laris et al. (2017) found that *B. pilularis* recruited heavily after mechanical removal of nonnative species. Mechanical removal is a common method used for invasive species control in restoration (Stromberg et al. 2007) and therefore may indicate at very least that some restoration activities can facilitate grassland woody invasion.

I was interested in the role that key restoration actions (singular planting and seeding) and drought had in influencing native woody shrub encroachment in grasslands by *B. pilularis* because of stark visual differences in *B. pilularis* cover observed 4 years posttreatment (Fig. S1). To test this, I took advantage of experimental plots at a coastal grassland in Santa Cruz, California, U.S.A. that were exposed to extreme drought, and previously restored experimentally though native species outplanting (Luong et al. 2021). I measured leaf functional traits (specific leaf area, major vein length per unit area, lobedness, and thickness) 4 years posttreatments and quantified the average stem diameter and abundance of *B. pilularis* 4- and 5-year posttreatment, and cover and recruitment 6-year posttreatment. I predicted that increase woody species encroachment (higher abundance of *B. pilularis*) would be promoted by singular restoration actions and be curtailed by drought. I hypothesized that *B. pilularis* would exhibit leaf trait adjustments that help explain its persistence through drought.

Methods

Study Site

The study was completed at the University of California Younger Lagoon Reserve (YLR) in Santa Cruz, California, U.S.A. The climate is characterized as Mediterranean with wet, cool winters and hot, dry summers. The area was historically utilized for cattle grazing and row crop agriculture before becoming a reserve in 1986. Legacy effects persist and the site is dominated by invasive species, notably *Avena barbata* Pott ex Link (Poaceae), *Festuca perennis* (L.) Columbus & J.P Sm. (Poaceae), *Bromus diandrus* Roth (Poaceae), *Medicago polymorpha* L. (Fabaceae), *Cirsium vulgare* (Savi) Ten. (Asteraceae), *Geranium dissectum* L. (Geraniaceae), and *Raphanus sativus* L. (Brassicaceae) with some native species, such as *Baccharis pilularis* (Asteraceae), *Erigeron canadensis* L. (Asteraceae), and *Elymus triticoides* Buckley (Poaceae).

Experimental Design

I utilized previously constructed rain exclusion (drought) shelters designed using a standardized protocol in 2015 as a part of the International Drought Experiment. Structures exclude 60% of incoming precipitation to simulate a 1-in-100-year drought after 5 years. These structures have been shown *in situ* induce drought with minimal nontarget effects, although they were documented to minimally reduce photosynthetically active radiation (PAR) and increase nighttime temperature by about 0.6°C (Loik et al. 2019). Rain exclusion plots were trenched and lined with 6-mil plastic to 50 cm depth to inhibit lateral water flow. The research plots are 3 × 3 m with a 0.5-m buffer around all edges resulting in a total 4 × 4 m area for each plot (Fig. 1). Plots were placed at least 1 m after accounting for buffer areas. Drought-induced reduction of soil moisture in these plots were confirmed in a previous field study with METER Environmental volumetric soil moisture probes (Luong et al. 2021). Standing biomass was removed via mowing from the research area and interstitial buffer areas prior to demarking twenty 4 × 4 m plots for the experiment. There was a full drought × restoration factorial design with five replicates for each treatment: (1) no experimental restoration and no drought (control; Fig. S1A); (2) experimental restoration only (Fig. S1B); (3) drought only (Fig. S1C); and (4) drought and experimental restoration (Fig. S1D). Plots were placed in an invaded annual grassland on area with visually similar vegetation, typically consisting of nonnative annual grasses and forbs, to avoid potential effects of site heterogeneity.

Experimental restoration included plantings that were previously installed as part of an ongoing experiment established in 2016 using a standard grid that was prerandomized (Luong et al. 2021). Because the original restoration experiment had different research goals, the planting design included three woody species to better assess the community level effect of drought on experimental restoration (Luong et al. 2021). The three woody species from the planting palette commonly occur in coastal sage scrub habitat that may naturally disperse into nearby grasslands, but are not often quick growing or invasive (Ford & Hayes 2007), unlike *B. pilularis* (McBride & Heady 1968), so they were not analyzed as encroaching woody natives. The 12 species were (Table S1) collected in 2015 from local reference sites and were grown in the UC Santa Cruz Jean H. Langenheim Greenhouses for about 3 months in "cone-tainer pots" (107 mL; Ray Leach—Stubby Cell Classic) in Pro-Mix Potting Soil Mix (Pro-Mix) prior to out-planting in January 2016. After planting, all nonnative plants were removed from restoration treatments manually with small hand tools once in January 2016 and a final time in April 2016. Buffer areas between plots were maintained through annual spring mowing,

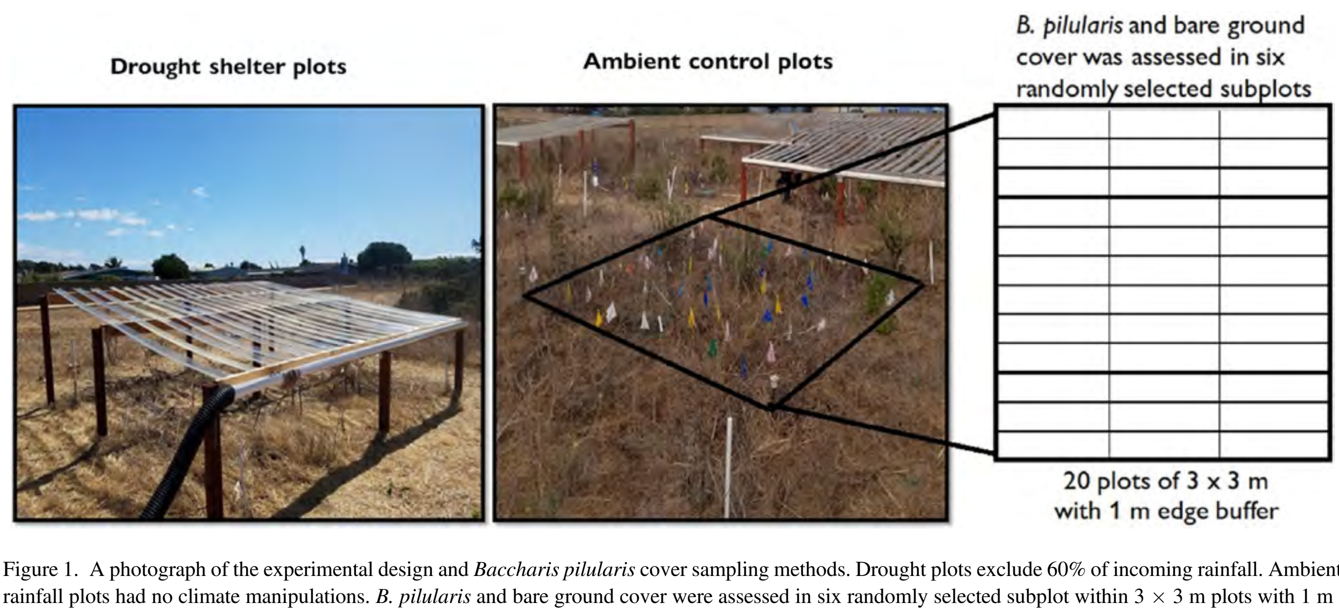

Figure 1. A photograph of the experimental design and *Baccharis pilularis* cover sampling methods. Drought plots exclude 60% of incoming rainfall. Ambient rainfall plots had no climate manipulations. *B. pilularis* and bare ground cover were assessed in six randomly selected subplot within 3 × 3 m plots with 1 m buffers around all edges.

but no other restoration activities were conducted on experimental plots after April 2016.

Data Collection

I assessed the cover of *B. pilularis* in 2021, the sixth year after planting, by estimating its relative cover to the nearest 5% within six 0.25-m^2 quadrats on each plot (Fig. 1). I also estimated the cover of bare ground within quadrats. I counted the total number of *B. pilularis* individuals within each plot in 2019 and 2020 (fifth and sixth year postplanting). I quantified leaf functional traits from five *B. pilularis* per plot in 2019, 4 years after initial treatments, and stem diameter for every individual in 2020. I collected leaves from up to four *B. pilularis* per plot to assess key functional traits and sampled two leaves per individual to account for variability. Leaves sampled were west facing, fully expanded, undamaged and three levels below the apical meristem on a given branch. Using standardized protocols, I measured specific leaf area (SLA), leaf thickness, major vein length per unit area (VLA), stem diameter, and leaf lobedness because they are related to plant hydraulics or water use (Hacke et al. 2001; Sack & Scoffoni 2013; Cadotte et al. 2015; see Pérez-Harguindeguy et al. 2016 for more detail on trait measurements). SLA is correlated with relatively high investments in structural leaf defenses and increased leaf lifespan. Major VLA of leaves can increase drought resistance by providing redundant pathways for hydraulic transport (Sack & Scoffoni 2013). However, increased VLA can also increase water requirements (Lambers et al. 2008), especially if the veins are not reticulated with minor vein networks. Leaf area and perimeter were measured using ImageJ software (Schneider et al. 2012). Leaf thickness was measured with a digital micrometer and is a proxy for higher mesophyll resistance against water movement through the leaf. Similar to VLA, the leaf thickness may have a mixed response to drought. Increased thickness can support more chloroplast and photosynthesis thereby increasing water demand (Lambers et al. 2008) but can also increase mesophyll resistance to water loss (Kröber et al. 2015). Higher leaf lobedness can effectively decrease the leaf air boundary layer increasing potential for cooling via convection and conduction (Lambers et al. 2008).

SLA was calculated as the ratio of fresh leaf area by oven-dried mass. VLA was quantified by measuring primary and secondary veins from fresh leaf scans using ImageJ and was standardized via fresh leaf area. Leaf lobedness was calculated as leaf perimeter squared divided by π and leaf area (Cadotte et al. 2015; Luong et al. 2021). Due to restrictions for in-person laboratory work from COVID-19, I was not able to collect and process leaf traits past year four (2019).

Analyses

All analyses were completed in R Statistical Software V 4.0.2 (R Core Team 2020) with base functions and the *plyr* and *ggplot2* packages (Kassambara et al. 2020; Wickham 2020). Data were tested for parametric assumptions prior to using *t*-tests, analysis of variance (ANOVA) or generalized linear models (GLMs). For count data, sampling year was included as a random effect. VLA was slightly nonparametric so I used a log-based transformation to meet statistical assumptions for a *t*-test, then back-transformed these data for visualization. No other measurements required transformation. Prior to analyzing functional traits, I averaged the values of the two collected leaves from the same individual. I then took the average of all measured individuals to calculate the mean at the plot level. All data were analyzed at the plot level ($n = 5$).

Results

The invading native shrub, *Baccharis pilularis* had higher abundance ($F = 20.1$, $df = 1$, $p < 0.001$) and cover ($F = 140$, $df = 1$, $p < 0.001$) on restored plots compared to unrestored control plots, which had no *B. pilularis* (Fig. 2). Drought resulted in lower individual *B. pilularis* counts on drought plots

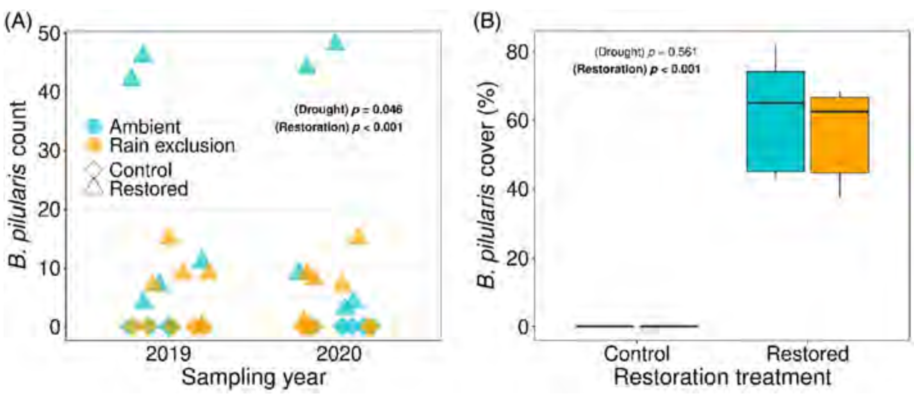

Figure 2. (A) Comparison of *Baccharis pilularis* counts 2019–2020. Points represent the count of *B. pilularis* in a given plot. (B) *B. pilularis* cover in 2021 for restored and nonrestored plots experiencing ambient (blue) or drought (orange) conditions. Boxes represents the interquartile range; the inner horizontal line represents the median. Lines extending out of the box represent the upper and lower quartiles. Points represent outliers. *p* values are presented within figures for drought and restoration treatments after respective text labels.

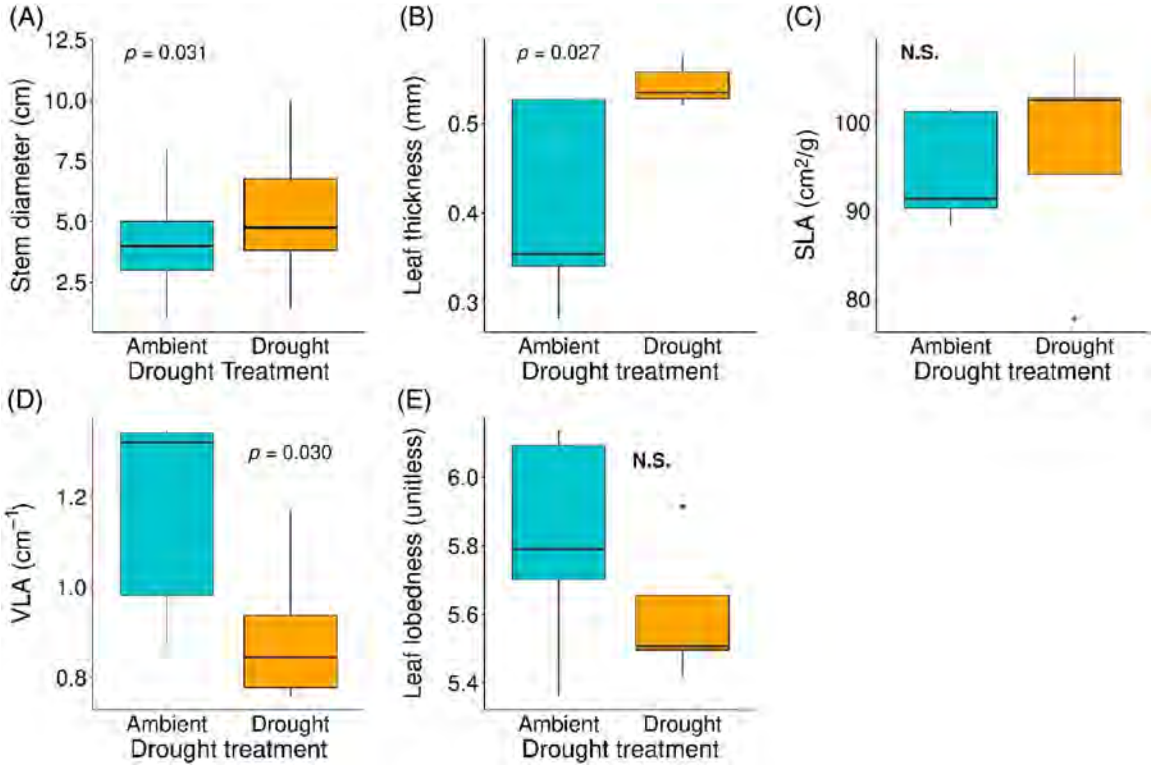

Figure 3. *Baccharis pilularis* (A) stem diameter (cm), (B) leaf thickness (mm), (C) SLA (specific leaf area; cm^2/g), (D) VLA (major vein length per unit area; cm^{-1}), and (E) leaf lobedness (unitless) compared between drought (orange) and ambient (blue) treatments. Leaf traits (B–E) were taken in 2019. Stem diameter was measured in 2020. Boxes represent the interquartile range; the inner horizontal line represents the median. Lines extending out of the box represent the upper and lower quartiles. Points represent outliers. N.S., nonsignificant.

($F = 4.30$, $df = 1$, $p = 0.046$), but did not affect cover values ($F = 0.352$, $df = 1$, $p = 0.561$). Abundance did not vary between years ($F = 0.001$, $df = 1$, $p = 0.976$).

B. pilularis exhibited adjustments for stem diameter ($p = 0.031$, $df = 56.48$, $t = -2.21$), major VLA ($p = 0.030$, $df = 7.37$, $t = 2.20$), and leaf thickness ($p = 0.027$, $df = 4.33$, $t = -2.64$), but not SLA ($p = 0.695$, $df = 6.16$, $t = -0.412$) nor lobedness ($p = 0.233$, $df = 6.69$, $t = 1.31$). *B. pilularis* had greater stem diameter and leaf thickness, but lower major VLA on drought plots (Fig. 3).

Bare ground cover increased on drought plots ($F = 7.73$, $df = 1$, $p = 0.013$), but was unaffected by experimental restoration ($F = 0.019$, $df = 1$, $p = 0.891$).

Discussion

Sixyears after initial treatments I found *Baccharis pilularis*-growing only in the restored plots, which indicates that restoration activities without ongoing management could facilitate woody shrub encroachment. Although periodic disturbance administered through grazing or prescribed burns can prevent woody species encroachment in grasslands (Smit et al. 2016; Hopkinson et al. 2020; O'Connor et al. 2020), nonperiodic disturbances have been found to positively correlate with *B. pilularis* abundance (Tyler et al. 2007; Laris et al. 2017). When practitioners are performing restoration either through invasive species removal or out-planting, they are creating small nonperiodic disturbances (D'Antonio et al. 2016) which could promote *B. pilularis* recruitment. However, these disturbances are likely supporting recruitment through mechanisms aside from baring ground and clearing open space for germination because the presented data show that drought resulted in decreased *B. pilularis* recruitment (albeit similar cover) despite increased bare ground cover. Soil disturbances often facilitate invasion of seed prolific species like *B. pilularis* because they germinate quickly and have high growth rates (McBride & Heady 1968; Pierce et al. 2017). Planting and invasive species control can also result in reduced soil compaction that facilitates invasion (Kyle et al. 2007).

Because grasslands are historically disturbance-dependent (Ford & Hayes 2007; De Bello et al. 2013; Stevens et al. 2017), especially in California, where grasslands were periodically burned by indigenous tribes as traditional ecological practices (Anderson 2007), the Intermediate Disturbance Hypothesis (IDH) may provide insight on the pattern I observed in this study (Connell 1978; Hobbs & Huenneke 1992). At this study site, the plots were only weeded twice in the first year after a singular planting event, and had no further management actions. The IDH predicts that infrequent or small disturbances are not large enough to maintain extant ecosystem dynamics. Extreme disturbances can push the system toward type conversion (Beisner et al. 2003), whereas moderate or intermediate disturbance is required to maintain the system and maximize diversity (Mayor et al. 2012). Indeed, results support that temporally limited experimental restoration was insufficient disturbance to limit *B. pilularis* recruitment, which may lead to decreased native species richness in later years (Van Auken 2009; Ratajczak et al. 2012). In accordance with IDH, allocating resources to implement a periodic disturbance regime may serve to manage woody species invasion. A review by Hobbs and Huenneke (1992) found that periodic disturbance can maintain and support higher taxonomic diversity, whereas Peterson and Reich (2008) found periodic fire was useful in preventing a gradual conversion of grasslands to forests. Fire employed as a periodic management practice increased native plant and avian diversity in a Brazilian grassland (Beal-Neves et al. 2020). Furthermore, an assessment of the savanna biome found that the occurrence of African savannas was correlated with areas with regular fire return intervals (Lehmann et al. 2011), whereas O'Connor et al. (2020) found fire can reduce the dominance of encroaching shrubs into a native grassland. Moreover, similar to our results, singular prescribed fires (disturbance), were found to promote woody invasion (Abella et al. 2020; Hopkinson et al. 2020).

B. pilularis recruitment was stunted by drought. It is plausible drought could potentially act as an annual or semiregular disturbance event (Derose & Long 2012) preventing type conversion as predicted by the IDH. However, studies from grasslands in both Texas and South Africa suggest that extended droughts may constrain and potentially reverse woody species encroachment (Twidwell et al. 2014; Case et al. 2020). In Australia, woody species encroachment was found to be slowed, but not reversed by extreme drought (Zeeman et al. 2014). Therefore, it is more likely that *B. pilularis* was not able to establish at high rates, in part, due to xeric conditions rather than drought acting as an intermediate disturbance. In fact, it has been observed elsewhere that woody invaders often establish better during wet periods (Williams et al. 1987; Browning et al. 2008).

Observed changes in hydraulic related functional leaf traits may explain, in part, how *B. pilularis* persisted through extreme drought and achieved similar cover as those from control plots at lower abundances. Alternatively, trait differences may be in response to reduced interspecific competition (Bolnick et al. 2011; Welles & Funk 2021). Rain exclusion resulted in *B. pilularis* having thicker leaves but lower major VLA to support reduced leaf water transpiration. Higher leaf thickness can decrease transpiration by increasing mesophyll resistance and reduced major VLA could lead to decreased rates of carbon assimilation and stomatal conductance thereby reducing water transport requirements (Lambers et al. 2008; Sack & Scoffoni 2013; Kröber et al. 2015). It is, however, possible that leaf thickness increased due to nontarget shelter effects (Loik et al. 2019) in response to reduced PAR resulting in compensatory photosynthesis (Lambers et al. 2008). In past work, stem diameter was shown to be negatively related to wood density (Markesteijn et al. 2011), and because increased wood density improves drought and cavitation resistance (Chave et al. 2009), higher stem diameter may promote more drought-related mortality (Twidwell et al. 2014). Stem diameter, similar to cover of *B. pilularis*, likely increased due to reduced intraspecific competition, because it increased as total *B. pilularis* abundance decreased.

These results are novel in documenting woody invasion by a native species following manual hand removal during active grassland restoration. They also support past research that indicates that certain restoration actions can promote woody encroachment into grasslands (Laris et al. 2017; Abella et al. 2020; Hopkinson et al. 2020). Experimental grassland restoration (via planting and nonnative species control) resulted in increased woody shrub invasion compared to nonrestored plots, and *B. pilularis* recruitment, but cover was not diminished, although not reversed by extreme drought. Restoration practitioners that work within coastal grasslands may consider revisiting restored grasslands after planted or an opportunistic targeted weeding event in a subsequent year to ensure their area is not being overtaken by woody species. Practitioners may also consider utilizing periodic prescribed burns which can slow woody species encroachment. In some cases, burns have been shown to reverse encroachment when applied with sufficient periodicity and intensity. Prescribed burns will also clear litter accumulation (Anderson 2007) which can promote species invasions in California grasslands (Stromberg et al. 2007). However, as previously noted, nonperiodic prescribed burns may further promote woody invasion (Abella et al. 2020; Hopkinson et al. 2020). When fire is not feasible, management may consider manual removal with regular return intervals. Spatially and temporally targeted grazing and mowing could also be employed to implement a regular disturbance regime to maintain grasslands. Further research about the rate of woody invasion following grassland restoration using agency implemented projects can indicate if this trend is consistent across larger spatial scales.

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Supporting Information

The following information may be found in the online version of this article:

Figure S1. A view from 2021 of each potential factorial treatment combination.
Table S1. The 12 California native planted species that were used in the restoration experiment, their family and life-form.

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RESEARCH ARTICLE

Adjustments in physiological and morphological traits suggest drought-induced competitive release of some California plants

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Abstract

Drought and competition affect how morphological and physiological traits are expressed in plants. California plants were previously found to respond less negatively to resource limitation compared to invasive counterparts. In a glasshouse in Santa Cruz, CA, USA, we exposed five native California C_3 grassland species to episodic drought and competition (via five locally invasive species). We hypothesized that leaf morphology would be more affected by competition, and leaf photosynthetic gas exchange more so by drought, consistent with optimal partitioning and environmental filter theories. We expected that traits would exhibit trade-offs along a spectrum for resource conservatism *versus* acquisition. *Bromus carinatus* had greater photosynthetic recovery, while *Diplacus aurantiacus* had lower percent loss of net assimilation (PLA) and intrinsic water-use efficiency (*i*WUE) during drought and competition simultaneously compared to just drought. *Stipa pulchra* and *Sidalcea malviflora* gas exchange was unaffected by drought, and leaf morphology exhibited drought-related adjustments. *Lupinus nanus* exhibited trait adjustments for competition but not drought. Functional traits sorted onto two principal components related to trade-offs for resource conservatism *versus* acquisition, and for above- *versus* belowground allocation. In summary, morphological traits were affected by competition and drought, whereas physiological traits, like leaf gas exchange, were primarily affected by drought. The grassland plants we studied showed diverse responses to drought and competition with trait trade-offs related to resource conservatism *versus* acquisition, and for above- *versus* belowground allocation consistent with optimal partitioning and environmental filter theories. *Diplacus aurantiacus* experienced competitive release based on greater *i*WUE and lower PLA when facing drought and competition.

KEYWORDS

competitive release, environmental filter, intrinsic water-use efficiency (*i*WUE), optimal partitioning, percent loss of net assimilation (PLA), $\delta^{13}C$

TAXONOMY CLASSIFICATION

Applied ecology; Ecophysiology; Functional ecology; Global change ecology

1 | INTRODUCTION

Optimal partitioning theory suggests that plants increase biomass allocation to structures that acquire the most limiting resource (Bloom et al., 1985). Stressors can differently affect physiological and morphological traits. Physiological traits are those related to molecular-level interactions of compounds within a plant, whereas morphological traits determine plant shape or structure (Lambers et al., 2008). Water-limited plants have been shown to partition growth more so to root than shoot structures (Liu & Stützel, 2004). Biotic stressors such as competition can have more varied impacts because it unevenly interacts with abiotic resources, which is further complicated by species-specific responses (Rehling et al., 2021). Invasive competition could lead to increased allocation to shoots or leaves to increase access to space and light (Pérez-Harguindeguy et al., 2016; Westoby, 1998), or increased allocation to roots to access limiting belowground resources, especially in abiotically harsh systems (Liu & Stützel, 2004; Poorter et al., 2012).

Droughts can lead to shifts in the root-to-shoot ratio (root:shoot) or adjustments in leaf traits related to resource conservative plant strategies (Heckathorn & Delucia, 1996). Plants that are more resource conservative typically grow slower, use less resources, and are more drought resistant, while resource acquisitive species may be more resilient in their recovery from drought or grow fast during wet periods to escape drought (Funk et al., 2008; Kooyers, 2015). Different mixes of acquisitive and conservative traits allow some species to recover from drought (Nicotra et al., 2010), while others may experience unrecoverable physiological stress (Zhong et al., 2019). Photosynthetic rates and biomass allocation are often reduced by drought, and although some species may recover photosynthetic rates fully upon rewetting, others may not (Poorter et al., 2012; Zhong et al., 2019). Certain plants have higher water-use efficiency (WUE) after drought (Lajtha & Marshall, 1994), whereas others have decreased WUE and lower photosynthetic recovery (Zhong et al., 2019) leading to feedbacks that can result in mortality.

Environmental filter theory (Funk et al., 2008) predicts that individuals have to pass through abiotic and biotic filters to establish or sustain co-existing populations at a particular site (Adler et al., 2013). Abiotic filters like drought often result in different species having similar conservative traits to survive the same harsh micrometeorological conditions. On the other hand, biotic filters facilitate species trait divergence, partitioning of resources, and allowing for species coexistence (Poorter et al., 2012). Passing through abiotic and biotic filters at a particular site may require contrasting values of the same traits (Funk et al., 2008; Pierce et al., 2017). Harsh abiotic conditions and limited resource availability select for resource conservative traits like low specific leaf area (SLA), stomatal conductance (g_s), and growth rates, whereas strong biotic filters associated with competition select for high net CO_2 assimilation (A_{net}), SLA, and high growth rates (Drenovsky et al., 2012; Pérez-Harguindeguy et al., 2016). Leaf lobedness and vein length can promote trait conservatism by reducing leaf water loss (Cadotte et al., 2015; Sack & Scoffoni, 2013). California will likely have more frequent droughts and continued species invasions that may lead to trade-offs that balance the selective pressures of opposing environmental filters (Ishida et al., 2008; Pierce et al., 2017; Seebens et al., 2015).

Strategies such as drought escape, avoidance, and tolerance are coordinated by physiological and morphological traits, and can be used to further understand plant responses to global change (Kooyers, 2015; Levitt, 1980). Drought tolerance and escape are more consistent with the classic leaf economic spectrum theory, while drought avoidance coordinates characteristics not typical of the leaf economic spectrum (Kooyers, 2015; Sandel et al., 2021; Volaire, 2018; Wright et al., 2004). Drought tolerance is more common for woody species with conservative traits (Ingram & Bartels, 1996; Volaire, 2018). Drought escape and avoidance are more common for herbaceous species with acquisitive traits that have active growth during periods of high soil water availability, distinct from drought-tolerant species that can maintain growth during periods with low soil water (Huang et al., 2018; Kooyers, 2015; Welles & Funk, 2021). Drought escape is common for annuals and is typified by quick growth and high fecundity (Huang et al., 2018). Drought avoidance is prevalent for both annuals and perennials, and these species rely on high WUE, limited vegetative growth, and high root:shoot ratio (Kooyers, 2015; Levitt, 1980).

Competitive release results in increased fitness or productivity for a species when its competitor is removed or negatively affected by environmental conditions (Menge, 1976; Segre et al., 2016). California plants may experience competitive release during drought because their invasive counterparts respond more negatively to drought compared to native annuals in greenhouses and perennials *in situ* (Luong et al., 2021; Valliere et al., 2019). Certain native perennial bunchgrasses are able to withstand competition from invasive species (Corbin & D'Antonio, 2004), but less is known about other life-forms. California species that are affected by invasion have lower aboveground productivity and some species adjust leaf traits associated with competitive ability to maximize fitness (Drenovsky et al., 2012; Seabloom et al., 2003). Yet, how invasive competition and drought interact to drive plant growth, morphology, and competitive release is less understood (Poorter et al., 2012; Segre et al., 2016).

We tested how drought and invasive competition shape functional traits and biomass allocation for five California grassland species commonly used for restoration in central California. In a controlled glasshouse environment in Santa Cruz, CA, USA, we measured physical traits (biomass, growth rates, specific leaf area, leaf area, major vein length per unit area, leaf lobedness, leaf C:N, and $\delta^{13}C$) and photosynthetic gas exchange rates (A_{net}, g_s) of native species experiencing episodic drought and invasive competition. Environmental filter theory predicts that plants will grow slower under drought, so we hypothesized droughted plants would have reduced instantaneous leaf-level gas exchange, and also greater root allocation due to optimal partitioning. We predicted that competition would lead to changes in leaf traits to acquire space and light resources. We also hypothesized native species would exhibit trade-offs that fall on a spectrum related to resource conservatism (high

VLA, lobedness, *i*WUE, and C:N; see methods) versus acquisition (high SLA, ARGR, A_{net}, and leaf N) observed via functional traits in response to factorial drought and competition, as predicted by the leaf economic spectrum and environmental filter theory.

2 | MATERIALS AND METHODS

The five native species in this study were chosen because they are commonly used for grassland restoration in California (Table 1; Jepson eFlora, 2020). We selected the five invasive species (Table 1) based on their high cover from previous vegetation surveys (Luong et al., 2021). The invasive species are regionally ubiquitous and monitored by the California Invasive Plant Council (www.cal-ipc.org). All seeds were sourced from experimentally restored areas at Younger Lagoon Reserve in Santa Cruz, CA, USA (36.951918°N, 122.063116°W; 7 m a.s.l.). Seeds were collected from multiple individuals on ambient rainfall (control) plots of a field drought experiment (Loik et al., 2019).

2.1 | Experimental design

We set up a two-way factorial study manipulating drought and competition from invasive species in a rooftop glasshouse at the University of California, Santa Cruz, between October 2019 and April 2020. In October 2019, we sowed seeds of native species (Table 1) on PRO-MIX high porosity soil (6:1:1 of sphagnum peat moss, perlite, and limestone) in seedling flats partitioned by species. Seedlings were kept well watered and then healthy seedlings similar in size from each species were individually transplanted into 32 4.5-L growing containers (17 cm tall × 16 cm diameter). Transplanting occurred at least 2 weeks after germination and after plants developed two sets of true leaves. Once transplanted, the native plants were well watered and unfertilized for 6 weeks. Because most fertilizers are water based, droughted plants could not be fertilized, so all plants were kept unfertilized. We randomized pot locations on the glasshouse tables weekly to limit microclimate effects. Average daytime temperatures and relative humidity (RH) were 16.5°C and 68.1% while nocturnal conditions were an average of 10.7°C and 78.4% RH. Proportions of light-to-dark hours started at 11 h light to 13 h dark in October 2019, slowly decreased to its minimum in December, with 9.5 h light to 14.5 h dark, and increased to reach 13 h light to 11 h dark at the end of the study in April 2020. We did not augment the light intensity or cycle.

Eight replicates of each species were assigned to treatments within a 2 × 2 factorial design: (1) well watered (no manipulation); (2) episodic drought; (3) invasive competition; and (4) invasive competition and episodic drought simultaneously. We harvested three replicates from each native species in each treatment group to determine baseline aboveground and belowground biomass during week 6, leaving five replicates per species in each treatment.

On week 6 we sowed five common invasive species (Table 1) in half of all pots to establish the competition treatment. We sowed invasives at densities based on historic field surveys (Heady, 1977; 185 mg per pot *C. pycnocephalus*, 100 mg *F. bromoides*, 103 mg *G. dissectum*, 85 mg *M. polymorpha*, and 69 mg for *R. sativus*) corrected for the surface area of a 4.5-L pot (201 cm^2). On week 8, we applied an episodic drought (Duan et al., 2014) where water was withheld until a minimum stomatal conductance (g_s; see list of abbreviations in Table 2) occurred for native species in an initial and secondary drought period (g_s <0.05 mol m^{-2} s^{-1} H_2O). Rehydration occurred concurrently for all individuals of the same species after half of the individuals droughted from that species reached the minimum g_s threshold. The g_s was measured for all native individuals using an open-mode portable photosynthesis system (Model LI-6400; Li-Cor, Inc.). Droughted plants were then rehydrated to pot capacity for 10 days, then exposed to a second drought. This episodic drought protocol with two drought periods has been shown to result in plant glasshouse drought responses that best mimic *in situ* plants (Duan et al., 2014). Due to interspecific variation in stomatal conductance to episodic drought (Table S1), the duration of drought varied for each native species. No native species had premature mortality. Non-natives used for the competition treatment persisted through the drought to the end of the experimental period (Table S1).

During the second episodic drought, native plants were maintained under treatments until at least half of the plants in the drought treatment reached g_s < 0.05 mol H_2O m^{-2} s^{-1}. All individuals of that

TABLE 1 Family, life-forms, and origin of the experimental grassland species

Scientific name	Family	Life-form	Origin
Diplacus aurantiacus Curtis.	Phrymaceae	Perennial semi-woody shrub	Native
Sidalcea malviflora (DC.) A. Gray	Malvaceae	Perennial rhizomatous forb	Native
Bromus carinatus Hook. & Am.	Poaceae	Perennial bunchgrass	Native
Stipa pulchra Hitchc.	Poaceae	Perennial bunchgrass	Native
Lupinus nanus Benth.	Fabaceae	Annual N-fixer	Native
Medicago polymorpha L.	Fabaceae	Annual N-fixer	Invasive
Festuca bromoides L.	Poaceae	Annual grass	Invasive
Carduus pycnocephalus L.	Asteraceae	Annual forb	Invasive
Raphanus sativus L.	Brassicaceae	Annual forb	Invasive
Geranium dissectum L.	Geraniaceae	Annual forb	Invasive

TABLE 2 Glossary of commonly used eco-physiological abbreviations

Abbreviation	Parameter
AGB	Aboveground biomass (g)
A_{net}	Leaf net CO_2 assimilation (μmol CO_2 $m^{-2}s^{-1}$)
ARGR	Aboveground relative growth rate (g·day^{-1})
ARR	Net CO_2 assimilation recovery rate (μmol CO_2 $m^{-2}s^{-1}$ day^{-1})
BGB	Belowground biomass (g)
BRGR	Belowground relative growth rate (g·day^{-1})
C:N	Leaf carbon:nitrogen ratio (unitless)
g_s	Leaf stomatal conductance (mol H_2O $m^{-2}s^{-1}$)
*i*WUE	Intrinsic water-use efficiency (μmol CO_2 mol H_2O^{-1})
PC	Principal component
PLA	Photosynthetic loss of net assimilation (%)
PRA	Photosynthetic recovery of net assimilation (%)
SLA	Specific leaf area (cm^2·g^{-1})
VLA	Major vein length per unit area (cm^{-1})
WUE	Water-use efficiency (μmol CO_2 mol H_2O^{-1})
$\delta^{13}C$	Carbon isotope fractionation (proxy for WUE, ‰)

species were then harvested for final biomass measurements. The experimental period lasted 73–130 days depending on the species.

2.2 | Functional traits

Traits were only sampled from native species. We collected three replicates of biomass from each species and treatment group prior to any treatments (week 6) and for all remaining individuals after the second episodic drought. We cut each plant at the base of the soil where the shoots and roots were differentiated. We washed soil out of the belowground biomass samples by gently dunking them in a series of four buckets with gentle agitation by hand. After the final bucket, we ran water over the roots to remove any remaining silt or perlite while over a 500 μm sieve to prevent root loss. We saved roots that broke off while washing to be included in dry biomass weights and estimated a loss of approximately 5% of total root biomass. Samples were dried at 60°C for at least 72 h before quantifying aboveground (AGB) and belowground biomass (BGB). We calculated aboveground relative growth rates (ARGR) and belowground relative growth rates (BRGR) by subtracting the final biomass of an individual by the baseline average taken in pretreatment (week 6), divided by the total growing days (Table 2).

We sampled leaves from native plants prior to any treatments and at the end of the second drought to quantify effects on specific leaf area (SLA), major vein length per unit area (VLA), leaf lobedness, leaf C:N, and $\delta^{13}C$ (see list of abbreviations in Table 2). Pretreatment leaf characteristics and biomass were used to confirm there was no grouping effect prior to experimental treatments (p_{all} > .05). SLA is related to photosynthetic ability, palatability, leaf life span, and growth rates (Sandel et al., 2021; Wright et al., 2004). SLA often decreases in response to drought but increases due to competition (Wright et al., 2004). Total leaf area is associated with competitive ability because it is related to light capture, shading, water loss, and energy budgets (Liu & Stützel, 2004; Pérez-Harguindeguy et al., 2016). Increased VLA can improve drought resistance by increasing vein reticulation and redundancy for water and sugar transport (Sack & Scoffoni, 2013). Leaf lobedness affects the leaf energy balance and is calculated as the ratio of leaf perimeter squared to the product of leaf area and π (Cadotte et al., 2015; Luong et al., 2021). Grass leaves may not be dissected but operationally, can have high leaf lobedness because of their high leaf perimeter:area ratios. Increased leaf lobedness decreases the effective length that wind travels at the leaf surface and reduces the boundary layer, resulting in increased cooling via conduction and convection, potentially decreasing leaf-level transpiration (Lambers et al., 2008). Leaf C is related to palatability and leaf N to photosynthesis (Pérez-Harguindeguy et al., 2016). Plants with high C:N values are often more resistant to drought but may be less competitive than plants with low leaf C:N (Drenovsky et al., 2012; Pérez-Harguindeguy et al., 2016). $\delta^{13}C$ is often used as a proxy for WUE (Table 2) because they are correlated for most species (Lajtha & Marshall, 1994).

We measured midday leaf gas exchange once prior to treatments, weekly during treatments (including the rewatering period), and once during dark hours (01:00 to 04:00 h) at the end of the second experimental drought period. For each species, midday measurements were conducted between 10:00 and 15:00 h. For each individual, we selected new but fully expanded leaves to use for gas exchange measurements, typically three levels below the apical meristem for cauline species. For bunchgrasses, we sampled leaves two levels outwards from the center and avoided leaves from flowering stalks. The order plants were measured were randomized weekly, so no treatment groups or individuals were consistently measured earlier or later in the day. We used a Model LI-6400XT portable photosynthesis system for all gas exchange measurements. Inside the leaf chamber, photosynthetically active radiation (PAR;

400–700 nm) was set at 1500 μmol m^{-2} s^{-1}, air temperature was 24°C, and CO_2 concentration was 400 μmol mol^{-1}. We started and calibrated measurements under identical glasshouse conditions (see above), took measurements only when the CV threshold was <0.2%, and acquired three instantaneous measurements at least 90 s apart to average for a certain leaf on a particular date. Intrinsic water-use efficiency (*i*WUE) was calculated as the ratio of net CO_2 assimilation (A_{net}) to g_s (Table 2).

The resistance and resilience of leaf-level photosynthesis (Zhong et al., 2019) were calculated as the percent loss of net assimilation (PLA; Equation 1) due to drought, and the percent recovery of net assimilation following rewatering (PRA; Equation 2). PLA and PRA are measured after the first drought period to provide a baseline for recovery after rehydration.

$$\mathrm{PLA}(\%) = \left(\frac{A_i - A_d}{A_i}\right) \times 100\% \quad (1)$$

and

$$\mathrm{PRA}(\%) = \left(\frac{A_r}{A_i}\right) \times 100\% \quad (2)$$

A_i, A_d, and A_r represent A_{net} prior to drought, the end of the first drought period, and after rewatering, respectively. The assimilation recovery rate (ARR) is related to drought resilience and was calculated with Equation (3), where D_r represents the number of days between A measurements. Because these measurements require a drought period, they were only calculated for plants in the drought and not well-watered treatments.

$$\mathrm{ARR} = \left(\frac{A_r - A_d}{D_r}\right) \quad (3)$$

2.3 | Analyses

All analyses were completed with R statistical software (Version 4.0.4; R Development Core Team, 2007). We ensured data had a Gaussian distribution and equal variances before using parametric tests. We used different statistical tests depending on the hypothesis to be tested. Data were processed and visualized with *plyr*, *cowplot*, and *ggplot2* (Wickham, 2020; Wickham et al., 2018; Wilke, 2020).

Because PLA, PRA, and ARR were only measured for individuals that experienced drought, the differences between droughted individuals with or without invasive competition were analyzed using *t*-tests. Traits (SLA, VLA, lobedness, C:N, δ^{13}C, and root:shoot biomass) collected at the end of the second drought period were compared using two-way analysis of variance (ANOVA) to test for interactive effects of drought and invasive competition. Competitive release was defined on a physiological basis where there was greater *i*WUE, ARR, PRA, or lower PLA during combined drought and competition, compared to when plants were exposed to drought with no competition (Segre et al., 2016). For data collected weekly (A_{net}, g_s, and *i*WUE), we used mixed linear models with time as a fixed variable to test for the effects of drought and competition over time. We used a regression to test for a correlation between δ^{13}C and *i*WUE.

We used a principal component analysis (PCA) to detect trade-offs between measured traits along a spectrum of two principal components (PC) using the *vegan* package (Ishida et al., 2008; Oksanen et al., 2018; Pierce et al., 2017). PCA can be used to decrease dimensionality in multivariate trait space by compressing multiple variables into fewer selected intercorrelated axes (principal components). Trait values were then tested for correlations against main PCs to determine intertrait relationships (Pierce et al., 2017; Table S2). Related traits are summarized into a singular PC with positively correlated traits on one end of the axis and negatively correlated traits along a diametrically opposed vector. Individual species (experimental units) plot near the traits for which they have high values on the PCA (Pierce et al., 2017). Within this study, the resulting ordination provides a first approximation of trade-offs between below- and aboveground growth (optimal partitioning) as well as resource and conservative traits (filter theory). Traits were categorized based on descriptions from Pérez-Harguindeguy et al. (2016). Funk et al. (2008), Sack and Scoffini (2013), and Poorter et al. (2012).

3 | RESULTS

3.1 | Growth responses

The root:shoot of all species, except *Bromus carinatus*, were significantly affected by invasive competition or drought (Figure 1, Table S1). *Diplacus aurantiacus* (p = .021) had lower root:shoot in drought, whereas *Lupinus nanus* (p = .015) and *Sidalcea malviflora* (p = .005) had higher root:shoot in response to invasive competition. *Stipa pulchra* had higher root:shoot from both drought (p = .004) and invasive competition (p = .001).

3.2 | Leaf traits

SLA and leaf δ^{13}C were the traits most responsive to drought and competition, while leaf lobedness was the least responsive (Figure 2). *Lupinus nanus* had lower SLA (p = .014), lower absolute leaf area (p = .002), higher VLA (p < .001), and higher leaf lobedness (p = .002) with invasive competition and higher δ^{13}C during drought (p = .016). *Diplacus aurantiacus* had smaller leaves (p < .001), but higher VLA (p < .001), C:N (p < .001), and δ^{13}C (p = .002) in drought. For the grasses, competition increased *B. carinatus* SLA (p = .047) and C:N (p = .041) while drought increased δ^{13}C (p = .043) and *S. pulchra* SLA (p = .004). The leaf traits of *S. malviflora* were unaffected by drought or competition.

3.3 | Photosynthetic gas exchange

Midday A_{net} and g_s of *B. carinatus*, *D. aurantiacus*, and *L. nanus* were negatively affected by drought, and further reduced for *L. nanus*

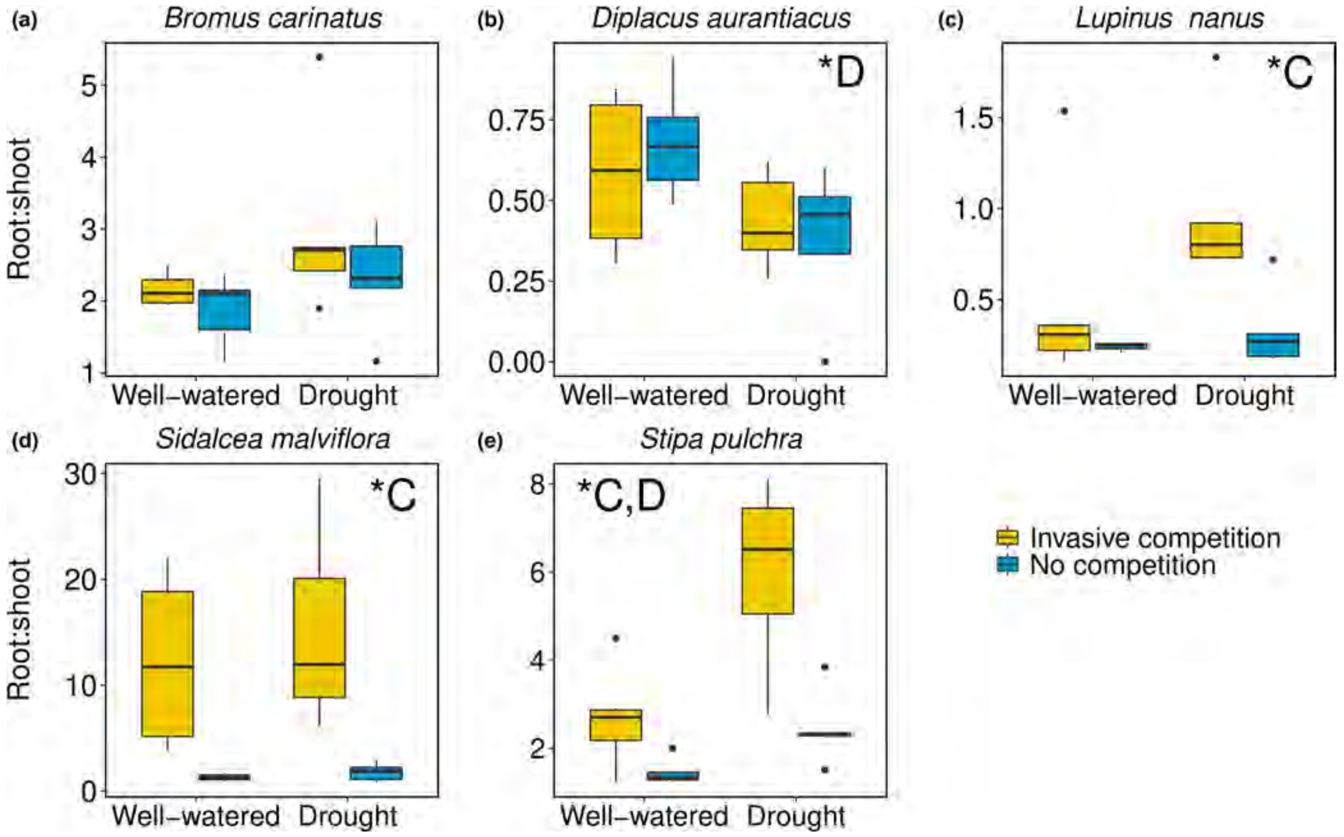

FIGURE 1 Root:shoot of native species: (a) *Bromus carinatus*, (b) *Diplacus aurantiacus*, (c) *Lupinus nanus*, (d) *Sidalcea malviflora*, and (e) *Stipa pulchra* when experiencing drought and competition from invasive species (yellow) or not (blue). *Denotes significance of C = competition, D = Drought; C, D indicates both competition and drought, but not the interaction (I). The colored bar = interquartile range; the solid line in the bar = median; lines extending out of bar = upper and lower quartile range; and circular points = outliers

through an interaction with competition (Table 3, Figure S2F–J). Drought decreased *i*WUE for *D. aurantiacus* and *L. nanus*, and was further limited by an interaction with competition for *L. nanus*. *Diplacus aurantiacus* had an interactive effect, resulting in higher *i*WUE for droughted plants only when experiencing competition (Table 3). Aside from interactions with drought, invasive competition did not affect leaf gas exchange. Midday A_{net} (Figure S2A-E) had a significant and negative reduction over time for all species except *B. carinatus*, whereas g_s decreased over time for all species but *B. carinatus* and *S. malviflora* (Table 3). *i*WUE had an inverse relationship with time for all species, except for *L. nanus*, which had greater *i*WUE over time, and *S. malviflora* which had no relationship with time (Figure S2K–O). Midday *i*WUE was positively correlated with leaf δ^{13}C of native species (p = .016; R^2 = .51; Figure S3).

Invasive competition increased nocturnal respiration for *D. aurantiacus* (p = .008) and for *S. pulchra* facing drought and competition simultaneously (p = .010), but no other species (Table S1; Figure S4). Nocturnal respiration was not affected for study species when only facing drought (p_{all} > .05). Nocturnal stomatal conductance was negatively affected by drought for *D. aurantiacus* (p = .040), *L. nanus* (p < .001), and *S. pulchra* (p = .004). Nocturnal stomatal conductance of *L. nanus* was further reduced by invasive competition in drought conditions (p = .012).

3.4 | Photosynthetic drought loss and recovery

Bromus carinatus (p = .046) and *L. nanus* (p = .001) had greater PLA from drought when experiencing invasive competition, whereas *D. aurantiacus* (p = .041) had lower drought-induced photosynthetic loss when in competition (Figure 3a). The recovery rate of assimilation (ARR; Figure 3b) was higher for *B. carinatus* (p = .039) and lower for *D. aurantiacus* (p = .019) during competition. Native species percentage recovery of A_{net} (PRA) was unaffected by competition (p_{all} > .05).

3.5 | Trade-offs in growth responses

We found that most traits grouped along two principal components (PC) that explained 40.3% and 22.4% of trait variance (Figure 4). Variances were not partitioned by treatments, but instead by species identity. PC1 was related to resource acquisition *versus* conservatism, which Kooyers (2015) related to strategies for drought escape *versus* tolerance (Kooyers, 2015). The acquisition end of the axis was correlated with high SLA, growth rates (ARGR and BRGR), midday A_{net}, and leaf %N. The resource conservative end of PC1 was related to high leaf C:N, VLA, and leaf lobedness (Table S2). PC2 was driven

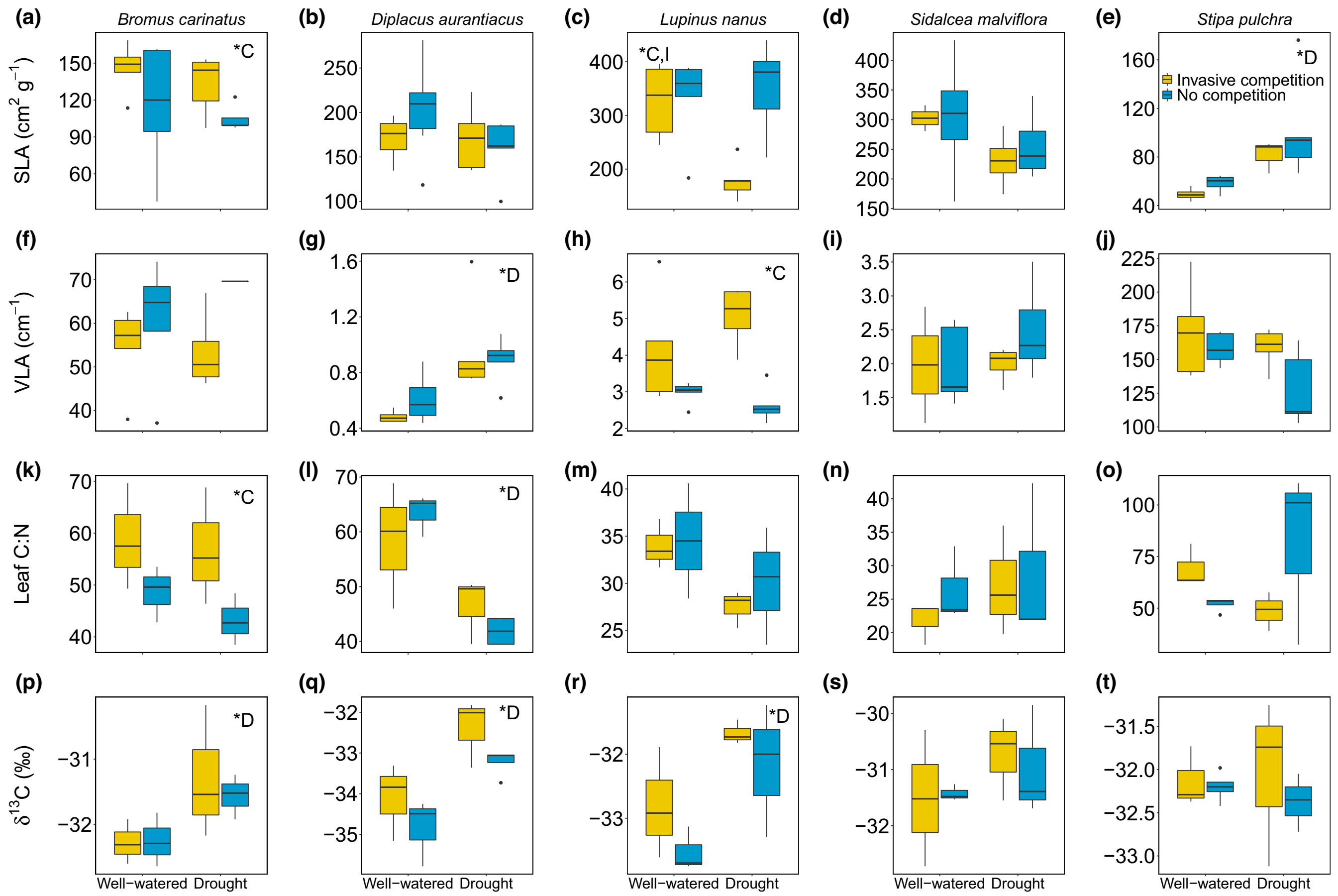

FIGURE 2 Functional traits (SLA (specific leaf area; a–e), VLA (major vein length per unit area, f–j), leaf C:N (k–o), and $\delta^{13}C$ (p–t)) for native species experiencing competition from invasive species (yellow) or not (blue). *Denotes significance of C = competition, D = Drought, or I = interaction. The colored bar = interquartile range; the solid line in the bar = median; lines extending out of bar = upper and lower quartile range; and points = outliers

by trade-offs related to above- *versus* belowground growth allocation. Allocation of resources belowground was associated with high root:shoot, *i*WUE, and $\delta^{13}C$, which contrasted with aboveground growth strategies that were correlated with high ARGR and leaf %C (Table S2). Nocturnal leaf respiration, nocturnal g_s, and midday g_s were not strongly related to either axis.

4 | DISCUSSION

Most greenhouse-grown native coastal grassland C_3 species that we studied exhibited drought-adapted trait adjustments and a limited amount of adjustments for competition. Our hypothesis that leaf gas exchange would be more affected by drought and less so by competition, and morphological leaf traits more to competition than drought was supported. Moreover, we found evidence (described below) that *D. aurantiacus* may experience competitive release during drought. Although it has been shown that drought in California can more negatively affect invasive species than natives, this may be the first evidence to show California species experiencing competitive release in a controlled environment. In support of our predictions and consistent with environmental filter theory, we found trade-offs between leaf trait conservatism *versus* acquisition. However, we also found trade-offs related to belowground *versus* aboveground allocation within the multivariate trait space, consistent with optimal partitioning theory.

4.1 | Invasive competition

According to optimal partitioning theory, increased allocation to roots in response to competition for *L. nanus*, *S. malviflora*, and *S. pulchra* suggests that belowground resources may be more limiting than light or aboveground space for these California coastal grassland species (Bloom et al., 1985; Poorter et al., 2012; Rehling et al., 2021). Aside from biomass allocation, we found certain species adjusted functional traits in response to competition. *Bromus carinatus* exhibited more acquisitive leaf traits (e.g., higher SLA), had more developed root systems to support higher resource needs, and recovered photosynthesis more quickly after drought when undergoing competition from invasives, indicating that this species may be useful for ecological restoration of heavily invaded areas. *Lupinus nanus* had lower leaf area and SLA, but higher VLA and lobedness in competition, which could indicate its sensitivity to competition.

TABLE 3 Significance (*p*-values) from midday leaf gas exchange analyses. Bold indicates significant values

Species	Treatment	A_{net}	*g*	*i*WUE
Bromus carinatus	Time	0.301	0.259	**<0.001**
	Well watered × Invasive competition	0.145	0.399	0.597
	Drought × No competition	**0.002**	**<0.001**	0.206
	Drought × Invasive competition	0.561	0.347	0.801
Diplacus aurantiacus	Time	**<0.001**	**<0.001**	**0.009**
	Well watered × Invasive competition	0.271	0.593	0.660
	Drought × No competition	**0.016**	**<0.001**	**<0.001**
	Drought × Invasive competition	0.396	0.105	**<0.001**
Lupinus nanus	Time	**<0.001**	**0.048**	**<0.001**
	Well watered × Invasive competition	0.114	0.294	0.900
	Drought × No competition	**<0.001**	**<0.001**	**0.032**
	Drought × Invasive competition	**<0.001**	0.126	**0.002**
Sidalcea malviflora	Time	**0.016**	0.930	0.428
	Well watered × Invasive competition	0.479	0.343	0.748
	Drought × No competition	0.945	0.116	0.076
	Drought × Invasive competition	0.501	0.490	0.791
Stipa pulchra	Time	**<0.001**	**0.011**	**<0.001**
	Well watered × Invasive competition	0.602	0.334	0.907
	Drought × No competition	0.341	0.865	0.943
	Drought × Invasive competition	0.875	0.849	0.845

Note: Treatment effects were compared using generalized linear models with a fixed time effect (based on weekly measurements). A_{net} = net CO_2 assimilation; g_s = stomatal conductance; *i*WUE = intrinsic water-use efficiency; *N* = 5 for all groups. All treatments were pooled to test for time effects, significance indicates change over time. Graphical representation (and direction of change) of these findings can be seen in Figure S2.

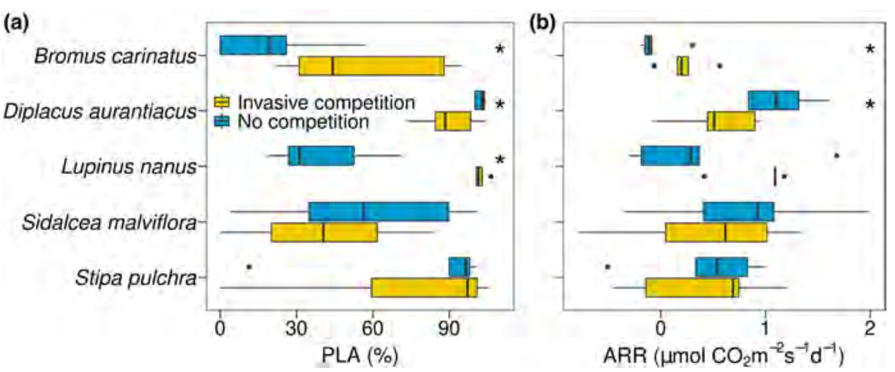

FIGURE 3 (a) PLA (the percent loss of assimilation) and (b) ARR (the assimilation recovery rates) of native species with competition from invasive species (yellow) or not (blue). *Denotes significant pairwise differences due to competition based on t-tests. The colored bar = interquartile range; the solid line in the bar = median; lines extending out of bar = upper and lower quartile range; and points = outliers

A combination of these traits could help increase retention of resources under high demand when contending with competition (Sack & Scoffoni, 2013; Sandel et al., 2021). Higher VLA could facilitate transport of water, photosynthates, and assimilated N (Sack & Scoffoni, 2013), while increased lobedness (Luong et al., 2021) and decreased SLA and leaf area (Pérez-Harguindeguy et al., 2016) can facilitate reduced transpirational water loss.

4.2 | Invasion during drought

Although *S. pulchra* increased root:shoot allocation in response to drought as predicted by optimal partitioning theory, *D. aurantiacus* showed an opposite response (Poorter et al., 2012). But *D. aurantiacus* can become woody over time, so investing resources aboveground could provide some degree of drought tolerance (Domec et al., 2017) and enhanced support to compete for light (Sun et al., 2003), and in this regard, responses are consistent with optimal partitioning. Increased $\delta^{13}C$ and *i*WUE during drought are consistent with upregulated drought tolerance (Lajtha & Marshall, 1994), and consistent with the spectrum of trade-offs exhibited by PC2 related to above- *versus* belowground growth allocation. *Diplacus aurantiacus* and *S. pulchra* had higher SLA during drought, which is unexpected based on classic leaf economic spectrum theory (Wright et al., 2004), but consistent with other research for plants in California (Sandel et al., 2021; Welles & Funk, 2021). Higher SLA is

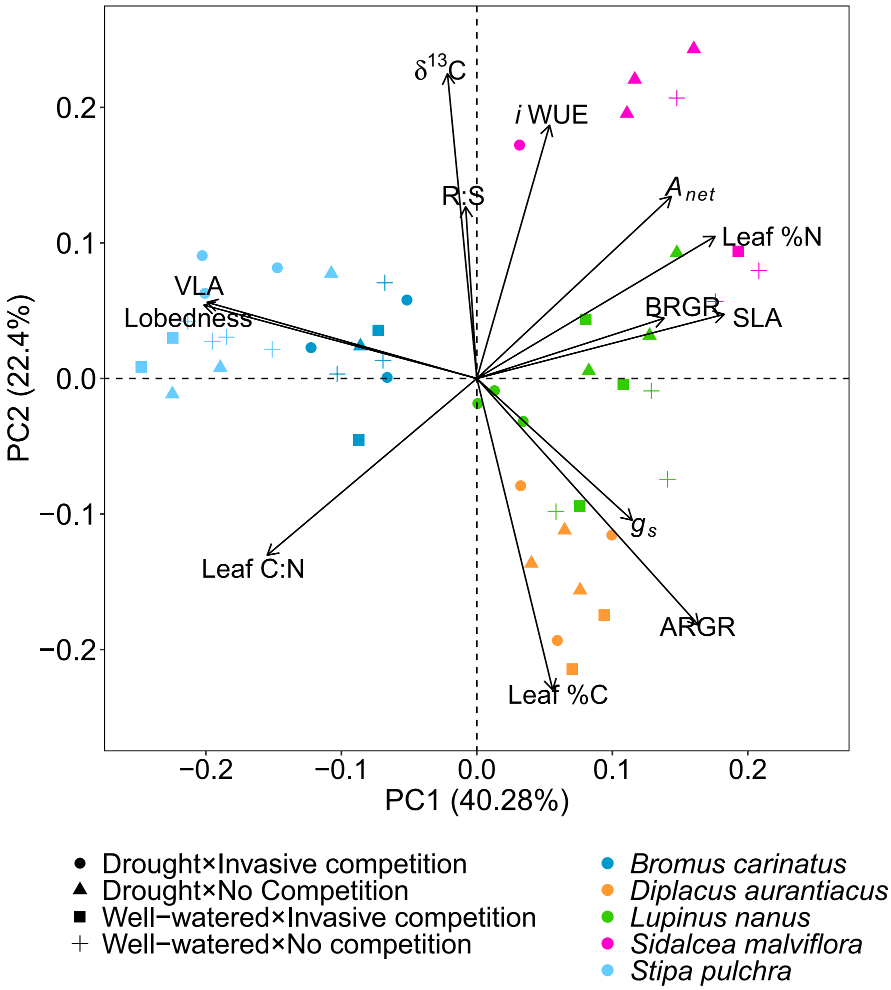

FIGURE 4 Principal components analysis (PCA) of native species traits experiencing drought and invasive species competition. Vectors indicate where values are highest. Points in the PCA represent the average trait space occupied by the individual plants measured in the experiment and plot within the PCA near vectors they have the greatest values for. Leaf C:N = ratio of leaf carbon:nitrogen; ARGR, aboveground relative growth rate; BRGR, belowground relative growth rate; R:S, dry root:shoot biomass ratio; SLA, specific leaf area; VLA, major vein length per unit area; A_{net}, net midday CO_2 assimilation; g_s, net midday stomatal conductance, and *i*WUE, midday intrinsic water-use efficiency. Units can be found in Table 2

related to resource acquisitive strategies (Funk et al., 2008; Wright et al., 2004) and possibly underlies drought escape (Kooyers, 2015), especially for plants in semi-arid environments. Indeed, other acquisitive traits (A_{net}, ARGR, BRGR, and %N) responded similarly to SLA in response to factorial drought and competition. Drought tolerance appears to be the strategy used by *D. aurantiacus*, as it often actively grows through the summer months and had more resource conservative traits (higher C:N and δ^{13}C). The pattern of trait relationships within the resource acquisitive *versus* conservative spectrum is consistent with environmental filter theory, whereas the trade-offs in above- and belowground allocation support optimal partitioning theory (Bloom et al., 1985; Funk et al., 2008).

In general, leaf gas exchange was negatively affected by drought and time, but not competition which supports environmental filter theory's prediction that growth will be more conservative during harsh conditions (Funk et al., 2008). Typically, physiological processes respond in shorter time scales compared to leaf morphology because physiological mechanisms are often molecular (Lambers et al., 2008), which may explain why gas exchange responded to drought. Physiological leaf traits (leaf C:N and δ^{13}C) were also primarily affected by drought and not as much by competition. Competition can have mixed effects depending on whether the invader is a stronger above- or belowground competitor (Poorter et al., 2012). Similarly, we found that native species exhibited morphological leaf trait (SLA, VLA, and lobedness) adjustments more often to competition, but in certain cases to drought. This response is consistent with optimal partitioning whereby individuals obtain limited aboveground light and space resources (Bloom et al., 1985; Drenovsky et al., 2012). In other instances, morphological traits were responsive to competition, and in a few cases to drought (Poorter et al., 2012). We also note that photosynthesis can decrease as plants age and do not need to compete for space as much as when they are younger (Stromberg et al., 2007).

Diplacus aurantiacus showed evidence of competitive release. Because certain invasive species respond more negatively to resource limitation compared to some California natives (Valliere et al., 2019), drought could have facilitated competitive release through increased drought resistance or photosynthetic recovery for natives. *Diplacus aurantiacus* had greater *i*WUE and lower PLA (percent loss of A_{net}) during drought (indicating higher resistance), but only when competing with invasives. The other native species may not have exhibited competitive release because they were able to adjust their root:shoot or other leaf traits as a result of competition.

5 | CONCLUSION

The focal native grassland species studied here had diverse responses to drought and invasive competition. Our results provide novel insight into how drought and invasive competition interact to support competitive release for *D. aurantiacus* in a controlled environment. Although each manipulation has been tested separately or jointly in the field, there was previously limited work indicating how the factors would interact to influence California plants in a controlled environment. Furthermore, we found morphological traits were primarily affected by invasive competition, whereas physiological traits like photosynthetic gas exchange were primarily affected by drought. Functional traits separated into two axes were related to resource acquisition *versus* conservatism, and aboveground *versus* belowground resource allocation. These relationships are consistent with optimal partitioning and environmental filter theories (Bloom et al., 1985; Funk et al., 2008; Poorter et al., 2012).

Our results have management implications for California grassland restoration and native habitat management. Because certain native species were more resilient or resistant to drought (*B. carinatus*, *S. malviflora*, and *S. pulchra*) and others were more sensitive (*L. nanus*), it may be resource effective for restorationists to use drought-adapted species if planting during extended drought periods, and limit introducing greater species richness to wetter years. Some may also consider using supplemental irrigation if sensitive species must be planted (Stromberg et al., 2007). *Bromus carinatus* exhibited beneficial trait adjustments for higher competitive ability, indicating it may be ideal to use in invaded areas. *Diplacus aurantiacus* showed evidence of competitive release, suggesting that these species will require less invasive species control during drought periods.

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CONFLICT OF INTEREST

Authors declare no conflict of interests.

AUTHOR CONTRIBUTIONS

Justin C. Luong: Conceptualization (equal); Formal analysis (lead); Funding acquisition (supporting); Methodology (supporting); Visualization (lead); Writing – original draft (lead). **Michael E. Loik:** Conceptualization (equal); Formal analysis (supporting); Funding acquisition (lead); Methodology (lead); Visualization (supporting); Writing – original draft (supporting).

DATA AVAILABILITY STATEMENT

Plant trait data were deposited in the TRY-TRAIT database. Data presented are available (including trait data on TRY-TRAIT) on PANGAEA Data Publisher for Earth and Environmental Sciences (Luong & Loik, 2022).

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SUPPORTING INFORMATION

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STUDENT RESEARCH
CNGA Grassland Research Awards for Student Scholarship Winner, 2019 & 2020
JUSTIN LUONG

Selecting Coastal California Prairie Species for Climate-Smart Grassland Restoration

by Justin C. Luong[1] and Michael E. Loik[1]

Abstract

California is predicted to experience warmer temperatures and more frequent droughts in future years, which will increase local and regional climatic water deficit. Understanding how commonly used restoration species will respond to drought may help with approaches to mediate the negative impacts of changing climates on restoration. Associated plant functional traits can increase understanding of how a group of species responds to variable environmental conditions, and aid with selecting broader mixes of drought-tolerant plants for restoration. For this study, we established ambient rainfall, first-year watered and drought treatments (60% rainfall reduction), in a coastal grassland in Santa Cruz, CA. Drought was created using rain-out shelters that simulate a 1-in-100-year drought. We planted 12 California native coastal prairie species to determine which species and life-forms had greater survivorship. We monitored the survival of these plantings annually from 2016 to 2019 and assessed the plant community composition in 2018 and 2019. We found that rhizomatous forbs were ideal candidates for planting coastal prairie restoration sites, especially in terms of drought. Bunchgrasses were also successful in the drought treatment, but to a lesser degree. N-fixers and non-rhizomatous forbs had minimal survivorship by the fourth year. Our findings demonstrate variable survival of planted seedlings in terms of time and drought. Additionally, from our study, the most favorable candidates for restoring California coastal prairie in a drier climate were common yarrow (*Achillea millefolium*), prairie mallow (*Sidalcea malviflora*), and purple needle grass (*Stipa pulchra*).

Background

Interannual rainfall variability, and other site conditions in the planting year, can play an important role in determining the outcomes of grassland restoration (Groves et al. 2020). California is warming and experiencing longer dry periods, portending a greater frequency of drought in future years (Cayan et al. 2007). This will increase local and regional climatic water deficit and increase plant drought stress (Loik et al. 2004), which may negatively impact restoration outcomes. To improve the success rate of restoration efforts, it may prove useful to develop restoration strategies that account for environmental variation, particularly as the climate continues to change.

Plants have adapted by developing functional traits that allow them to survive abiotic and biotic stressors in the environment. Traits can help with selecting species for restoration that are more suitable for establishment in variable and changing climates (Pérez-Harguindeguy et al. 2016). Functional traits can include morphological features of leaves, shoots, or roots; physiological processes such as photosynthetic rates; or life-form descriptions like "bunchgrass" or "shrub." Life-form classification is a framework, readily accessible through the Jepson eFlora, for describing species that tend to have similar overall morphologies (Pérez-Harguindeguy et al. 2016).

The coastal prairie, a special type of grassland that receives coastal fog during the summer, is one of the most diverse grassland types in North America (Ford and Hayes 2007). Restoration of these habitats is often mandated by the California Coastal Commission through the California Coastal Act of 1976, so it is important to understand the factors that limit the success of these restoration efforts. Some species might be better adapted than others for drier conditions in coastal prairies and focusing on those species could help meet strict compliance goals.

In this study, we manipulated ambient rainfall to assess the impacts of extreme drought and first-year watering on 12 native California coastal prairie species. We planted experimental plots with seedlings in 2016 and monitored them for four years to compare survival, to determine whether certain prairie species or life-forms had higher survivorship. We hypothesized that drought would positively benefit planted native species, first-year watering would increase survival of seedlings, and non-rhizomatous forbs would have the lowest survivorship of the life-forms we studied.

Methods

Study Site

Younger Lagoon Reserve is a mesic coastal terrace prairie in Santa Cruz, CA, that has experienced various anthropogenic disturbances (grazing, tillage, row-crop agriculture) since the 1800s. It was protected as part of the UC Natural Reserve System in 1986. The reserve currently has ongoing restoration efforts that include non-native species control and plug plantings with local genotypes of native species. The area is dominated by non-native species such as Italian thistle (*Carduus pycnocephalus*, forb), brome fescue (*Festuca bromoides*, annual grass), Italian rye grass (*Festuca perennis*, annual grass), rip-gut brome (*Bromus diandrus*, annual grass), cutleaf geranium (*Geranium dissectum*, forb), and wild radish (*Raphanus sativus*, forb), with some remnant native species like coyote scrub (*Baccharis pilularis*, shrub) and coastal tarweed (*Madia sativa*, forb). Restoration efforts

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adjacent to the study site have successfully increased the abundance of native prairie species such as California brome (*Bromus carinatus*, bunchgrass), blue wild rye (*Elymus glaucus*, bunchgrass), creeping wild rye (*Elymus triticoides*, rhizomatous grass), purple needle grass (*Stipa pulchra*, bunchgrass), common yarrow (*Achillea millefolium*, rhizomatous forb), pacific aster (*Symphyotrichum chilense*, rhizomatous forb), and many coastal shrub species.

Younger Lagoon Reserve has a Mediterranean climate with summer coastal fog. During the four years of the experiment, rainfall in the hydrologic year (October–September) was around the long-term average (1981–2010) of 796 mm (Western Regional Climate Center: **https://wrcc.dri.edu**). Years 1, 2, and 4 had rainfall within 20% of the long-term average; specifically, years 1 (643 mm) and 4 (695 mm) had slightly below, and year 2 (954 mm) had slightly above average rainfall. Year 3 (521 mm) was a dry year and had 35% less rainfall than the long-term average.

Drought Manipulation

Drought shelters were constructed in summer 2015 following the standardized protocol from the International Drought Experiment (Knapp et al., 2015; **drought-net.colostate.edu**). Drought (rain-out) shelters exclude 60% of incoming rainfall, thereby simulating a 1-in-100-year drought based on historic Santa Cruz precipitation. Shelters were built with metal and wooden frames and polycarbonate troughs that lead water into gutters away from the plots (Loik et al. 2019). Drought plots were trenched 50 cm deep on all four sides and lined with 6-mil plastic to limit influence from lateral water flow and root growth. Drought shelters have little effect on air temperature, relative humidity, and reduce daily total photosynthetically active radiation by 20% (Loik et al. 2019). All plots were 4 × 4 m with a 0.5-m buffer on each side, creating a 3 × 3 m experimental area. Treatment effects on volumetric soil water content were confirmed using one soil moisture probe in each treatment 15-cm deep (METER Environmental; formerly Decagon, Pullman, WA, USA). We set up five plots of each treatment type: drought, ambient rainfall, and first-year watering. First-year watering is a common practice for restoration in arid regions when resources are available (Stromberg et al. 2007). First-year watering was used to determine if it could increase the long-term survivorship of native plantings. Planted natives in first-year watering plots were hand-watered with 4 liters twice in the first growing season (2016) during a rain-gap period in February, then March.

Plots were mowed to remove all standing biomass and then were planted with 12 native species (three to seven individuals per species) in January 2016. Seedlings were grown in containers in glasshouses for about three months at the UCSC Plant Growth Facility from seeds collected ≤40 km from our site (Table 1). Native species were selected based on reserve recommendations and to maximize life-form diversity. Native seedlings were planted in a randomized grid so that all plots had an identical planted species arrangement at the start of the experiment. Species life-forms were identified using the Jepson eFlora. After planting, research plots were weeded twice during the first growing season and not again after. Weeding included hand removal of non-native species using planks suspended above the plots to reduce plot disturbance.

Table 1. The 12 California native species planted for the study.

Taxa	Common Name	Life-Form
Achillea millefolium	common yarrow	rhizomatous forb
Artemisia californica	California sage scrub	shrub
Bromus carinatus	California brome	bunchgrass
Diplacus aurantiacus	sticky monkey flower	shrub
Ericameria ericoides	mock heather	shrub
Eschscholzia californica	California poppy	forb
Hosackia gracilis	harlequin lotus	N-fixer
Lupinus nanus	sky lupine	N-fixer
Lupinus variicolor	many-colored lupine	N-fixer
Sidalcea malviflora	prairie mallow	rhizomatous forb
Sisyrinchium bellum	blue eyed grass	forb
Stipa pulchra	purple needle grass	bunchgrass

Survivorship & Species Composition

We quantified survival annually every April from 2016 to 2019. Survivorship was determined as the proportion of individuals that survived, as a function of total individuals planted.

In 2018 and 2019 we surveyed plant community composition in six permanent quadrats (0.25 × 1 m) established through randomized grid selection in each plot. Absolute plant cover was estimated to the nearest 5% with a modified Braun-Blanquet method. Absolute plant cover includes multiple canopy heights to ensure that all species are surveyed, so cover values can exceed 100%. We also recorded thatch cover and depth, and the absence/presence of seedling recruitment from the 12 planted species.

Analyses

All analyses were completed with the statistical analysis package, R (v3.6.1). Data were tested for parametric assumptions before using analysis of variance (ANOVA) or generalized linear models (GLM). ANOVAs were used to test for differences between the mean survival of different treatments, and GLMs were used to test for linear relationships between variables. Thatch depth and cover were directly correlated ($R^2 = 0.21$, $p = 0.007$), so we used thatch depth for subsequent analyses. We used Bray-Curtis dissimilarities to compare treatment effects on plant communities between plots from 2018 and 2019, then used the similarity of percentages (SIMPER) analysis to determine the contribution of individual species to the overall degree of community dissimilarity (Qureshi et al. 2018).

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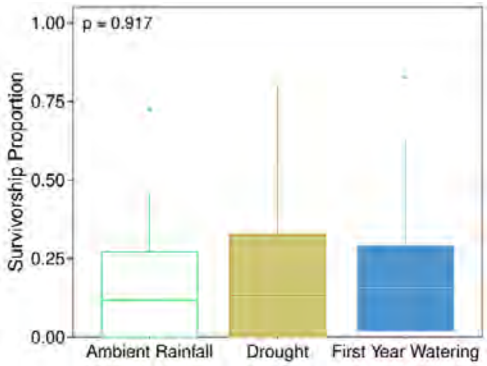

Figure 1. Survivorship compared across treatments for all 12 planted native species combined during year 4. Box represents interquartile range, the bar in the box represents the average, whiskers represent upper and lower quartiles of the data range, points represent outliers.

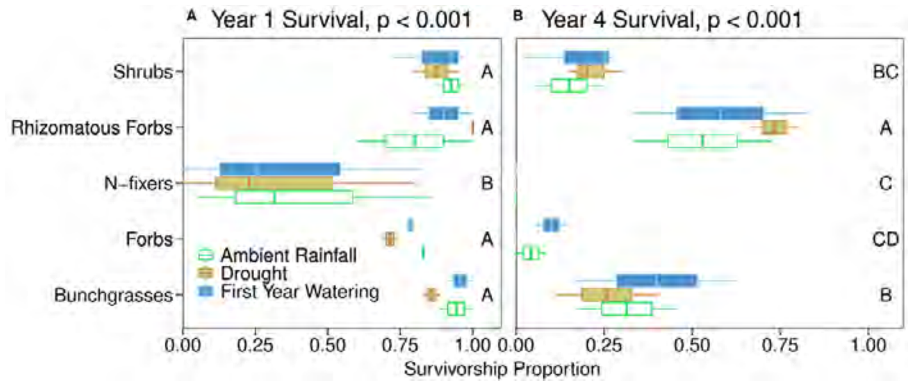

Figure 2. Survivorship in April of (A) year 1 (2016) and (B) year 4 (2019) compared across treatments for 12 planted species by life-form. Inset p-values are from the ANOVA model test: *'survival~life-form'*. Non-overlapping letters represent significant differences in survivorship between life-forms in respective panels. Survivorship of N-fixers (and forbs on drought plots) in year 4 was zero, thus it is plotted on the y-axis. Differences in survivorship by treatment within each life-form group are not noted in this figure. See Figure 1 for box-plot interpretation.

Selecting Coastal California Prairie Species for Climate-Smart Grassland Restoration *continued*

Results

Planting Survival

We found that both drought and first-year watering had no effect on survivorship compared to ambient rainfall plots four years after planting (Figure 1).

We found that there were significant differences in survivorship between life-forms by the end of the first (2016) and fourth (2019) growing seasons when treatments were combined (Figure 2). Nitrogen-fixing species had lower survivorship than all other life-forms ($p_{all} < 0.001$), but no other differences between life-forms were found at the end of the first growing season. By the end of the fourth growing season, rhizomatous forbs had the highest survivorship (70.1%) across treatments compared to other life-forms ($p_{bunchgrass} = 0.022$, $p_{N\text{-}fixer} < 0.001$, $p_{shrub} < 0.001$, $p_{forb} < 0.001$). Bunchgrasses had higher survivorship than forbs ($p = 0.031$) and N-fixers ($p = 0.004$), but not shrubs ($p = 0.409$). Shrubs, forbs, and N-fixers had similar survivorship by the end of the fourth growing season.

We then looked for treatment effects within each life-form grouping and found only forb survivorship was negatively affected by drought treatment after the first growing season ($F = 9.8$, $p = 0.044$), although not by the end of the fourth. No other survivorship differences by treatment within specific life-form groupings were noted in years 1 or 4.

The nitrogen-fixers (harlequin lotus, sky lupine, and many-colored lupine) and blue-eyed grass had no survivors nor any seedling

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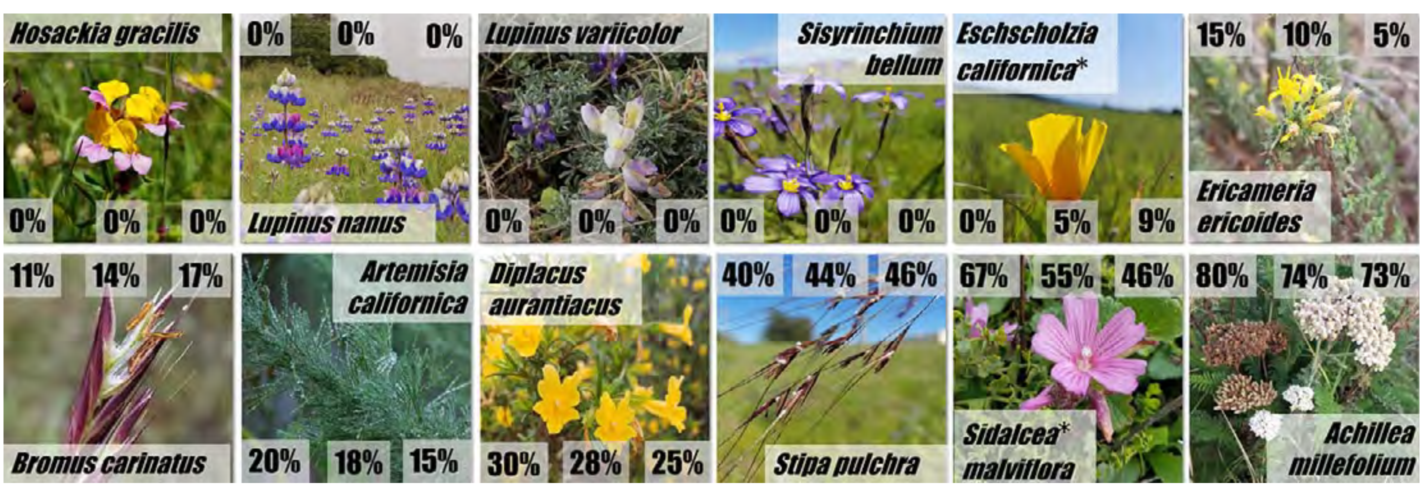

Figure 3. Survivorship of the 12 native species at the end of the fourth growing season. Survivorship from left to right in each panel represents drought (left), overall average for treatments combined (center), and ambient rainfall (right). Survivorship from first-year watering plants is not depicted since there was no effect. Significant differences in survivorship between drought and ambient rainfall plots occurred only for *S. malviflora*.

Selecting Coastal California Prairie Species for Climate-Smart Grassland Restoration *continued*

recruitment by the fourth year (Figure 3). The California poppy had some recruitment, but only 5% of the originally planted cohort survived at the end of the fourth growing season. Notably, the California poppy was the only planted species that was somewhat negatively affected by drought (p = 0.069). Mock heather, a fall-flowering shrub, also had low survival and no recruitment. The bunchgrasses, California brome and purple needlegrass, had moderate survivorship, and both showed some recruitment, especially *B. carinatus*. Summer-flowering shrubs, *Artemisia californica* and *Diplacus aurantiacus*, had moderate survival, though lower than bunchgrasses (Figure 3). The rhizomatous forbs, *Sidalcea malviflora* and *Achillea millefolium*, had high survivorship by the end of year 4. *Sidalcea malviflora* showed evidence of seedling recruitment and had higher survivorship in drought compared to other treatments (p = 0.012). Both rhizomatous forbs had considerable vegetative spread through rhizomes, especially *A. millefolium*. All other species were unaffected by drought, and the survivorship of no species showed signs of benefitting from first-year watering at the end of the fourth growing season.

Plant Community Differences

We used Bray-Curtis dissimilarities to compare community composition on the plots, and summarized the findings in Figure 4.

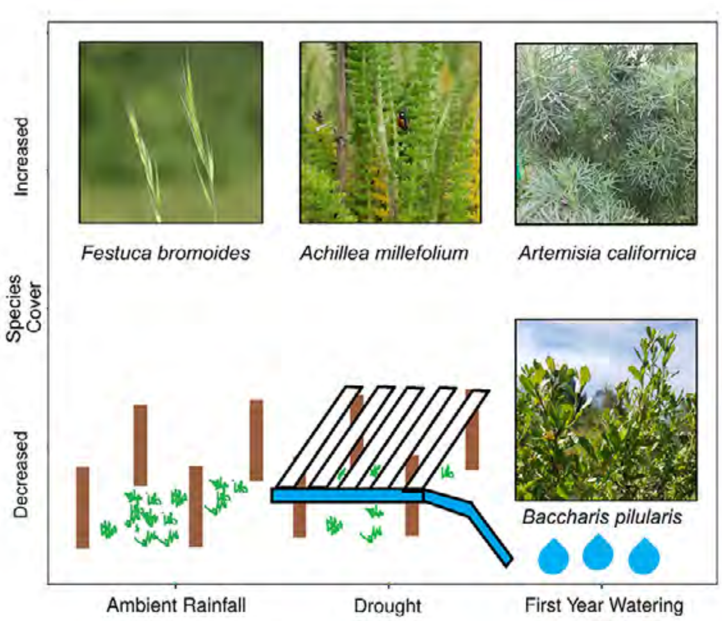

Figure 4. Certain species were found to underlie the differences in plant community composition between treatments (results from similarity percentage breakdown (SIMPER) analysis). Species in each treatment column are significant for determining how their plant communities are dissimilar from others. Species in the top row had greater cover in their respective treatment, and those in the bottom row had lower cover.

Plant communities on drought plots were significantly different from that of ambient rainfall and first-year watering plots, while the latter two had mostly overlapping plant communities ($k = 3$, stress = 0.117). We found that certain species explained the differences in community composition (SIMPER; p < 0.001). On drought plots, *Achillea millefolium* had 31% cover, which accounted for 21% of community difference between drought and ambient rainfall plots, which only had 6% *A. millefolium* cover (p < 0.001). *Achillea millefolium* explained 18% of the variance between drought and first-year watering plots, which had 11.3% average cover (p = 0.003). *Festuca bromoides* (a non-native annual grass) explained 12% of the plant community difference between ambient rainfall and drought plots (p = 0.011). Ambient rainfall plots had 21% *Festuca bromoides* where the cover and drought plots had 13% (p = 0.011). *Baccharis pilularis* explained 12% of community variation between first-year watering and ambient rainfall plots (p = 0.050). First-year watering plots had 9% cover and ambient rainfall had 14% cover. First-year watering plots had greater *Artemisia californica* cover (6%) which explained about 5% of the community difference compared to both drought (1%; p = 0.011) and ambient rainfall plots (1%; p = 0.010).

Native species cover was negatively correlated with thatch depth (Figure 5). We did not find any significant linear relationships between thatch and total non-native species cover, annual grass cover, nor any specific dominant extant non-native species.

Discussion

Overall, native plant survivorship decreased over the four years for the 12 native species, demonstrating the difficulty of restoring native coastal prairie. It is unlikely that precipitation patterns over the four

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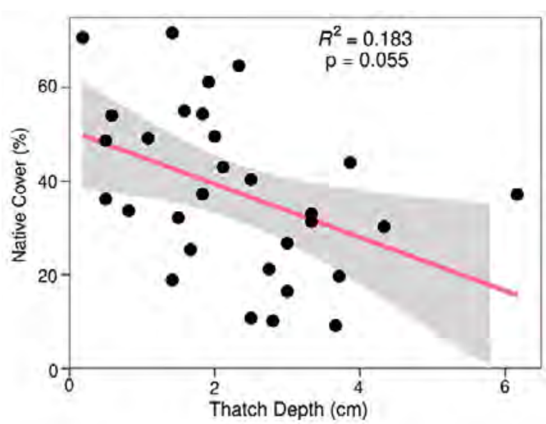

Figure 5. The relationship between native species cover and thatch depth. Points represent plots in 2018 and 2019. The shaded region represents a 95% confidence interval.

Selecting Coastal California Prairie Species for Climate-Smart Grassland Restoration *continued*

years led to this outcome, as survivorship trends do not match the inter-annual rainfall totals. Survival and cover were unaffected by the drought treatment for most of the native species. Low survivorship could have been a result of other things such as competition or diseases at earlier life stages. Alternatively, low survivorship could have been caused by background weather conditions which could have caused drought stress. But, the competition hypothesis is consistent with previous work that indicates California natives are sensitive to competition as seedlings which could result in low survival (Buisson et al. 2006). However, certain life-forms had higher cover or survivorship on drought plots than others. For example, the rhizomatous forb common yarrow had higher cover, whereas prairie mallow had high recruitment and was the only one of 12 species that had higher survivorship in drought plots. These rhizomatous forbs could be useful in establishing native cover to meet short- and long-term restoration targets or mandated compliance goals, even in drought years.

Some of the native species had minimal recruitment and establishment by year four, including the non-rhizomatous forbs, the California poppy, blue-eyed grass, and the N-fixing forbs. N-fixing forbs had lower survivorship than all other life-forms after the first growing season. Despite obvious benefits from nitrogen inputs, N-fixers may not be the best species for rapidly increasing native cover. The California state flower, the California poppy, was the only species to be negatively affected by drought compared to ambient rainfall plots during all four study years. This could indicate a need for future management of this species if there are more frequent or longer droughts. The responses of bunchgrasses were mixed, with purple needle grass having relatively high survivorship and California brome exhibiting high recruitment. These results are similar to past studies showing the general difficulty of establishing forbs in California grasslands (Copeland et al. 2016).

Since thatch depth is weakly and negatively associated with native species cover, periodic thatch or litter removal could help ensure the persistence of native prairie species. Other studies have found that thatch can suppress California native species growth, especially in the early years (Reynolds et al. 2001). Thatch is often associated with reduced recruitment of natives among non-native species (Hayes and Holl 2003). However, although thatch accumulation was unsurprisingly lower in drought plots (Zavaleta and Kettley 2006), we found no correlations between the native and non-native species and thatch at the study site.

Managing species that drive community change may be a good starting point for restoration actions. In this experimental system, this happened to be common yarrow and brome fescue. Common yarrow accounted for the higher native cover in drought plots, while ambient rainfall plots had a high cover of brome fescue, a non-native annual grass. Brome fescue may be an important target for weed management during average rainfall years whereas common yarrow could be useful for increasing native plant cover in dry years.

Management Recommendations

Our results demonstrate that certain plant species or life-forms may be better suited than others for the restoration of coastal prairies. We recommend managers that have short-term native compliance goals to use life-forms with high survivorship such as the rhizomatous forbs *Achillea millefolium* and *Sidalcea malviflora*. Bunchgrasses can persist for years after planting, and some, like *Bromus carinatus*, had high seedling recruitment. Managers with an immediate compliance goal in the second year might consider avoiding life-forms with low survival and/or seedling recruitment, such as non-rhizomatous and N-fixing forbs. When possible, coastal grassland managers should consider how to further incorporate non-rhizomatous forbs into their planting plans. Lastly, managers may also consider periodic thatch removal to promote higher native species cover.

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Applying empirical dynamic modeling to distinguish abiotic and biotic drivers of population fluctuations in sympatric fishes

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Abstract

Fluctuations in the population abundances of interacting species are widespread. Such fluctuations could be a response to abiotic factors, biotic interactions, or a combination of the two. Correctly identifying the drivers is critical for effective population management. However, such effects are not always static in nature. Nonlinear relationships between abiotic factors and biotic interactions make it difficult to parse true effects. We used a type of nonlinear forecasting, empirical dynamic modeling, to investigate the context-dependent species interaction between a common fish (three-spine stickleback) and an endangered one (northern tidewater goby) in a fluctuating environment: a central California bar-built estuary. We found little evidence for competition, instead both species largely responded independently to abiotic conditions. Stickleback were negatively affected by sandbar breaching. The strongest predictor of tidewater goby abundance was stickleback abundance; however, this effect was not a uniform negative effect of stickleback on goby as would be hypothesized under interspecific competition. The effect of stickleback on gobies was positive, though it was temporally restricted. Tidewater goby abundance in the summer was strongly positively correlated to stickleback abundance in the spring, which represents an offset in the reproductive and recruitment peaks in the two species that may help minimize competition and promote coexistence. Our study demonstrates how empirical dynamic modeling can be applied to understand drivers of population abundance in putative competitors and inform management for endangered species.

Both abiotic and biotic factors can drive population fluctuations (Grant et al. 2016; Šipoš et al. 2017; Morris et al. 2020). Understanding which drivers are acting on a given population is important for understanding resilience, estimating population viability, and managing endangered species (Sinclair and Byrom 2006; Traill et al. 2010). Abiotic factors such as climate and habitat degradation may limit population abundance or cause fluctuations in population size (Chavez et al. 2003; Lemoine et al. 2007; Kearney et al. 2010). Alternating population cycles of pairs of species may be taken as evidence for alternative responses to abiotic forcing variables such as climate (Chavez et al. 2003). Alternating cycles may be due to populations having different optimal values of fluctuating environmental variables, different seasonal patterns, or a combination thereof.

Biotic interactions, such as competition, predation, or parasitism may also influence the abundance of a focal population (Bardsley and Beebee 2001; McGraw and Furedi 2005; Rogowski and Stockwell 2006). However, disentangling abiotic and biotic drivers, especially when those potential drivers fluctuate, can be challenging (Sugihara et al. 2012; Gabaldón et al. 2019). Mirage correlations can occur when the relationship between predictor and population response is state dependent (Deyle et al. 2013). For example, determining whether abiotic conditions or biotic interactions are driving population fluctuations may be difficult if the presence of an interacting species depends on certain abiotic conditions (Rogowski and Stockwell 2006) or if interaction strength changes as a function of those abiotic conditions (Alcaraz et al. 2008; Jiao 2009; Deyle et al. 2016a).

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Additional Supporting Information may be found in the online version of this article.

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The magnitude of interaction strengths such as competition coefficients, and even the identity of the dominant competitor can change as a function of the environment (Stewart and Levin 1973; Dunson and Travis 1991; Muench and Elsey-Quirk 2019). Coexistence may depend on changes in the identity of the competitive dominant under fluctuations in environmental conditions (Hutchinson 1961). Typically, understanding such context-dependent species interactions requires conducting manipulative experiments under diverse environmental conditions which may be impractical when threatened and endangered species are concerned (Costanzo et al. 2005; Muench and Elsey-Quirk 2019).

Empirical dynamic modeling, a type of nonlinear state space reconstruction, can be used to overcome these challenges using time series data (Sugihara et al. 2012). Such time series of abundance data is regularly collected for monitoring of some threatened and endangered species. Multivariate s-map projection, a type of empirical dynamic modeling analysis, sequentially estimates the partial derivatives of the response variable with respect to each predictor variable over time. When response and predictors are the abundance of two species, these partial derivatives can be interpreted as a measure of time-varying interaction strength such as competition coefficients (Sugihara 1994; Deyle et al. 2016b). Such measures of interaction strength can be used to assess numerical population responses to competition. For the purposes of this study, competition is defined as a numerical response of one population's growth rate as a function of the other species' density.

The habitat and abiotic conditions in bar-built estuaries in central California undergo dramatic seasonal fluctuations leading to episodic opening and closure (Williams and Stacey 2016). Bar-built estuaries, or lagoons, are intermittently connect to the ocean during the wet seasons but will dry up when the rains stop and the runoff runs out; then a sandbar or berm will form, disconnecting the estuary from the open ocean (Behrens et al. 2009, 2013; Rich and Keller 2013). The bathymetry can change extensively during cycles of breaching and closing (Webb et al. 1991; Elwany et al. 1998; Orescanin and Scooler 2018). These physical changes to the shape of the estuary basin, from flowing and river-like during the winter to still and pond-like during the summer are accompanied by changes in the physicochemical properties of the estuary such as temperature, dissolved oxygen, and temperature and may include changes to stratification (Williams and Stacey 2016). Dissolved oxygen can reach anoxic conditions during the summer dry period.Northern tidewater goby (*Eucyclogobius newberryi*) are a federally threatened species that is a habitat specialist adapted to living in bar-built estuaries (Swenson 1999). Such specialization does not mean they are immune from mortality during extreme environmental conditions such as hypoxia or breaching (Williams and Stacey 2016; Swift et al. 2018). Tidewater goby populations fluctuate dramatically (Swenson 1999).

Three-spine stickleback (TSS; *Gasterosteus aculeatus*) may function as competitors for tidewater gobies. In bar-built estuary habitats both species primarily consume benthic macroinvertebrates (Swenson and McCray 1996; Sánchez-Gonzáles et al. 2001). In laboratory experiments stickleback presence negatively affected tidewater goby survival, but only when food resources were limiting (Chase et al. 2016; Chase and Todgham 2016). TSS are a common and widespread species, not restricted to bar-built estuary habitats (Bell and Foster 1994).

Here we use empirical dynamic modeling to separate the effects of abiotic and biotic drivers on tidewater goby and TSS population abundance. We ask whether stickleback and goby interact (compete) or are independently responding to environmental drivers. Second, we ask whether environmental conditions can cause changes in the interaction strength between stickleback and gobies. For example, the relationship between stickleback and goby abundance may depend on a third value, such as temperature, with competition stronger during warm weather, but weaker during cool weather.

Methods

We surveyed fish in Younger Lagoon monthly from February 2014 through September 2020. Younger Lagoon is a 10-ha bar-built estuary, which is noteworthy in being unimpeded by habitat alteration such as channelization or anthropogenic breaching (Clark and O'Connor 2019). Younger Lagoon experiences annual breaching cycles as described above. In addition, during the dry, warm summer conditions, the lagoon is often densely populated by a primary producer. In many years, that is the submerged vegetation *Ruppia*, but other years a phytoplankton bloom occurs. Anoxic conditions may occur in the late summer as the producer biomass begins to senesce and decay, especially overnight.

We placed 12 unbaited minnow traps (40.5 cm long, 22.9 cm diameter at the center, with 3 mm mesh, and openings with a diameter of 22 mm) along the eastern shore of the lagoon in the evening and retrieved them the next morning. Minnow traps were allowed to sink to the substrate. We did not place minnow traps in fixed locations. Instead, location was allowed to vary along the shoreline to prevent fish mortality since fluctuating water levels led to seasonal changes in habitat and anoxia risk. The front of the lagoon (the channel on the beach) was generally the deepest, the large central basin was less shallow, and the two upstream arms were the most shallow. When conditions warranted (warm temperatures and the potential for low oxygen), we varied the depth of water we set out traps in. As such we often moved them away from shore into deeper water. In the extreme, during hot summers and fall months, our traps in the central basin were placed along the thalweg (the deepest channel), and few if any traps were placed in the upstream arms because they were too shallow for the traps to even remain submerged. We counted the number of each species of fish encountered in each trap and report the average catch per unit effort for each survey.

Starting in September 2014, we measured the surface water temperature, salinity, and dissolved oxygen (percent saturation) using a YSI Pro2030 at a subset of the trap locations, usually every other trap. We used linear interpolation to fill in missing data due to equipment failure (1 salinity measurement and 2 dissolved oxygen measurements).

Rainfall data were provided by the University of California Natural Reserve System (https://ucnrs.dendra.science/). Rainfall was summarized for the water years 1991–2020 (water year starts on 01 October of the preceding calendar year, https://water.usgs.gov/nwc/explain_data.html). Data on estuary breaching were taken from an automated camera that photographed the lagoon mouth every 15 min during daylight hours. Photos were available for water years 2014–2020. We manually searched all photos available during the wet season to identify breaches. The lagoon does not breach during the dry season. Overnight breaches were detected by observing differences in mouth morphology from evening until morning photos. We augmented missing data with personal observations taken during the surveys and other visits to the lagoon. To determine whether breaching dynamics are primarily driven by within-year variation in rainfall, or cumulative effects of rainfall (such as multiyear droughts) we used an ANOVAANOVA to test for the effect of total rainfall and Accumulated Drought Severity and Coverage Index (https://droughtmonitor.unl.edu/) on the log-transformed total number of days open in a given water year; because the interaction term was not significant we removed it.

Drivers of fish abundance

To understand which environmental drivers influence stickleback and goby abundances, we used empirical dynamic modeling, a set of tools for understanding nonlinear processes from time series data (Sugihara and May 1990; Sugihara 1994; Sugihara et al. 2012; Ye and Sugihara 2016). Empirical dynamic modeling uses time-lagged values of the measured variables to reconstruct the attractor of the underlying dynamic system based on generalized Taken's theorem (Sugihara and May 1990; Deyle and Sugihara 2011). We can then use this graphical model to make predictions and use measures of cross-validated prediction accuracy (rho, R^2) to compare alternative models (Deyle et al. 2013). For empirical dynamic modeling analysis we used a time series from September 2014 to September 2020. Our focal variables were the mean number of stickleback and tidewater goby caught per trap. Potential environmental drivers included the total amount of precipitation that had fallen (rain), the total number of days the lagoon was documented as open (breach) since the last survey, and the mean of temperature, dissolved oxygen, and salinity weighted by the number of traps associated with each measurement. We normalized all variables to mean 0 and standard deviation 1 to compare the relative importance of drivers measured on very different scales.

We used convergent cross-mapping to identify which, if any, of the environmental variables, including the abundance of the other species, influence the abundance of the two focal species (Sugihara et al. 2012). In convergent cross-mapping, lags of the focal variable are used to make predictions about the state of a hypothesized driver (target variable) via simplex projection. If that target variable's states can be predicted by using lags of the focal variable then we say the focal variable cross-maps onto the target and that is evidence that the target variable exerts causal influence on the focal variable (Sugihara et al. 2012). We used this procedure to evaluate which target variables causally influence the abundance of each fish species. The embedding dimension (number of lags we used) for each species was the optimal embedding dimension for predicting the abundance of that species using a univariate simplex projection model (Sugihara and May 1990). To test whether the cross-mapping was significant, we compared the forecast accuracy for the target variable (cross-map skill, measured as *rho*, the Pearson correlation between predicted and observed values) from the model to cross-map skills derived from a null distribution (Deyle et al. 2016a). We created the null distribution of cross-map skills from 1000 surrogate time series by extracting a mean seasonal trend with a smoothing spline and then shuffling the residuals.

If the abundance of a focal species (e.g., gobies) is driven primarily by abiotic factors, then we would expect it to only cross-map onto abiotic factors (e.g., temperature or dissolved oxygen). Alternatively, if competition is important in driving focal species abundance, then we would expect it to significantly cross-map onto the abundance of the other species (e.g., stickleback). If the focal species abundance significantly cross-maps to both abiotic factors and biotic factors then both are important for driving the abundance of the focal species and we can use s-map regression to determine whether those effects are merely additive, or whether they are interactive (i.e., context-dependent competition) (Deyle et al. 2016b).

Drivers of interaction strength

To test whether interaction strength between the two fish species varies with environmental conditions, we used another empirical dynamic modeling technique, s-map regression (Sugihara 1994). Multivariate s-map projection sequentially estimates the Jacobian matrix of partial derivatives of the response variable with respect to each predictor variable over time and can be interpreted as a measure of time-varying interaction strength (May 1973; Deyle et al. 2016b). For each species we ran a number of multivariate s-map projections to predict species abundance at time $t+1$. All models included two "seasonal predictors": s_t and s_{t-3}, to account for seasonal variation (Rogers et al. 2020). The seasonal predictors were two sine functions (mean 0, variance 1) offset by 3 months, with a period of 1 yr and a timestep of 1 d, which used the sample date and the sample date from three samples earlier as input variables (e.g., if s_t was the date of the April sample, then s_{t-3} was the date of the January sample). We then searched through a set of candidate models that included all possible combinations of those two seasonal predictors, lags of the two species abundance, and lags of any other predictors variables that the focal species was found to significantly cross-map to. We ran all possible combinations of lags for each predictor up to E, the univariate embedding dimension for the focal species (e.g., with two variables, we could have $2 + 3E$ predictors: 2 seasonal variables, and E lags of two variables $+ E$ lags of the species itself). S-map projection requires a nonlinear tuning parameter, θ, which indicates the

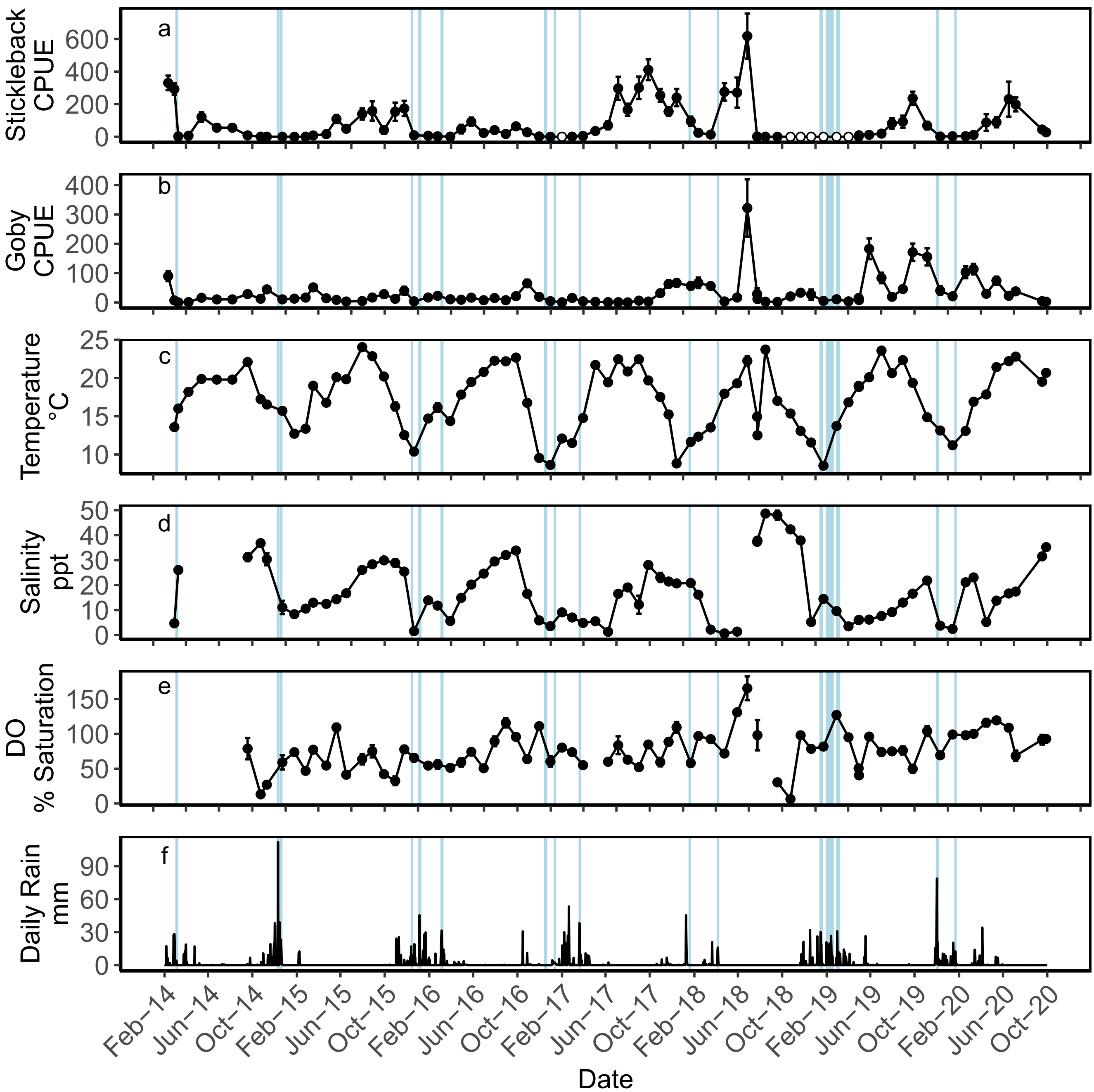

Fig. 1. Time series from monthly fish surveys and water quality monitoring. Blue shading indicates days for which known breaches occurred. Points show mean values, error bars depict one standard error. (**a**) Stickleback catch per unit effort (CPUE), (**b**) tidewater goby CPUE, (**c**) temperature (°C), (**d**) salinity (parts per thousand), (**e**) dissolved oxygen (percent saturation), (**f**) daily rainfall (mm).

Table 1. ANOVA table for log-transformed number of days open per water year against predictors: Accumulated Drought Severity and Coverage Index (ADSCI) and annual rainfall (mm).

Predictor	SS	Df	*F*	*p*
ADSCI	0.30411	1	1.9031	0.2398
Annual rainfall	1.15491	1	7.2273	0.0548*
Residuals	0.63919	4		

*alpha = 0.10.

relative weighting of points nearby in predictor space (Sugihara 1994). A value of $\theta = 0$ represents an unweighted global model where all points contribute equally to predictions, whereas a larger value of θ means points nearby in predictor space are more heavily weighted. For each model (set of predictor lags) we chose the best value of θ between 0 and 20 based on prediction accuracy (R^2). We then picked the best model for predicting the focal species by choosing the one with the highest prediction accuracy (R^2).

We extracted the coefficients from this best model for each species, which represents a time series of partial derivatives for the focal species with respect to each predictor. Coefficients describing the relationship between species represent time-varying interaction strengths between them (Deyle et al. 2016b). However, since the variables were normalized to compare the relative importance of drivers measured on very different scales, they are not exactly interchangeable with per-capita interaction strengths determined experimentally, rather they are more analogous to standardized regression coefficients and are useful in determining the relative importance of predictors (Paine 1992; Laska and Wootton 1998). We used an ANOVA to determine if either of the season variables or any of the environmental variables we measured were associated with the interaction strengths between the two species. Significant effects of

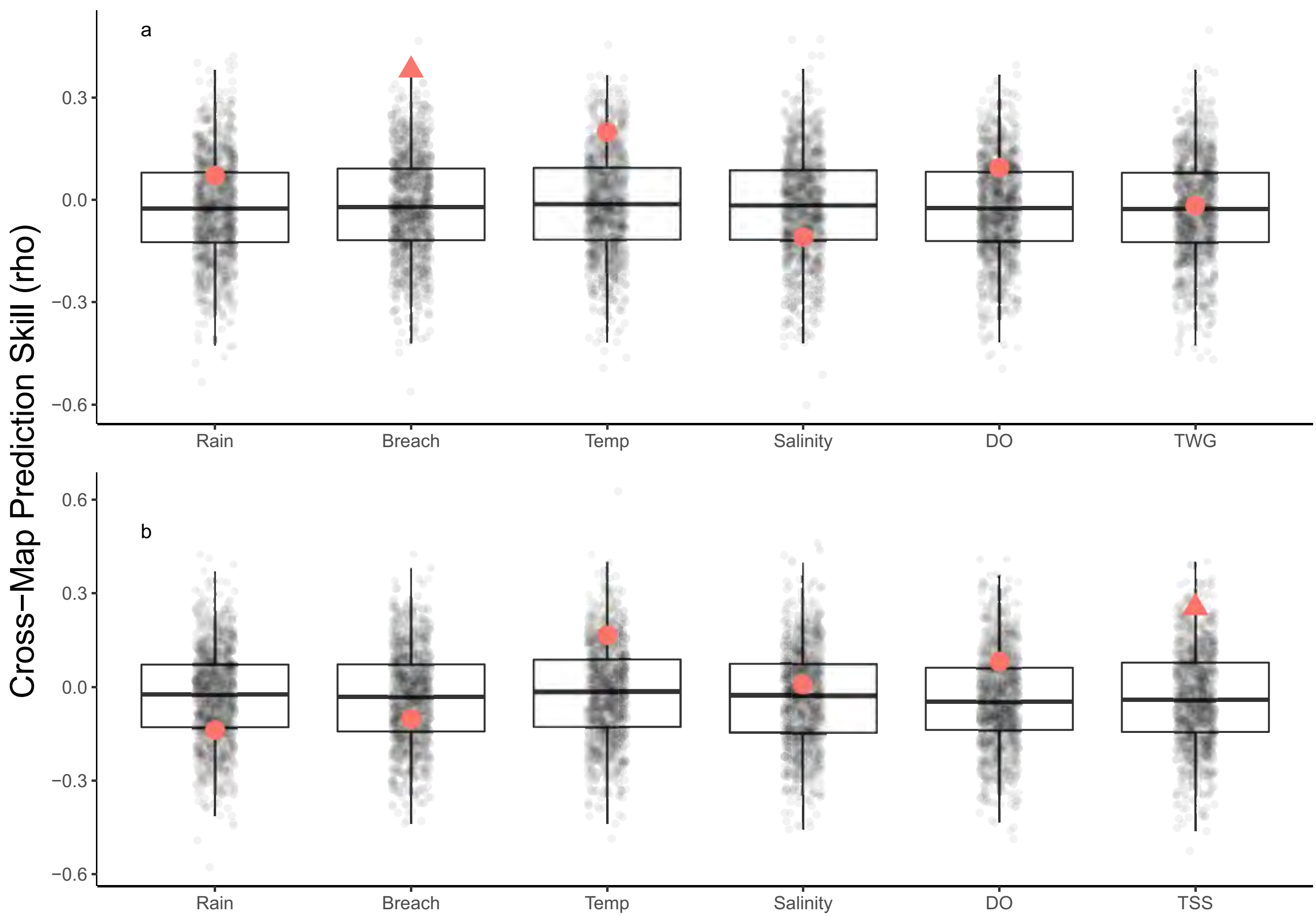

Fig. 2. Convergent cross-map forecast skill (*rho*), red symbols, circles are not significant and triangles are significant ($p < 0.05$) when compared to seasonally-matched null distributions (black boxes and scatterplots) for (**a**) threespine stickleback (TSS), and (**b**) tidewater goby (TWG). Predictors include monthly rainfall, number of days open (Breach), temperature, salinity, dissolved oxygen (DO), and the abundance of the other species of fish.

environmental variables on interaction strengths would be considered evidence of context-dependent competition. We checked for multicollinearity using variance inflation factors, all were less than 5.

Results

Stickleback and tidewater goby catch per unit effort fluctuated by three orders of magnitude (Fig. 1a,b), generally increasing in the spring and summer and crashing in the late summer, fall, or winter. No stickleback were encountered for 6 months from September 2018 through March 2019. It is not possible to distinguish whether the population persisted at low levels or whether it truly went extinct in fall of 2018 and was recolonized during the open phase of winter 2018–2019. In the spring of 2019, after several months with no stickleback captures, tadpoles of two species of amphibians, Pacific Chorus Frogs (*Pseudacris regilla*) and California Red-legged Frogs (*Rana draytonii*) were captured and swarming cladocerans (*Daphnia magna*) were observed in the shallows but were not observed at any other time during this survey.

Rainfall varied seasonally as expected (Fig. 1f). Winters were characterized by rainfall that led to decreased salinity, and temperature, and eventually led to one or more breaching events (Fig. 1). Dry summer seasons were characterized by increased temperature, increased salinity as water evaporated from the isolated lagoon, and, in some cases, anoxia (Fig. 1c–f). Our fish surveys span most of the range of variation in annual rainfall at Younger Lagoon; they ranged from the 4th wettest to the very driest years in the 25 years with sufficient data (Fig. S1a). In addition, drought monitor data reveal that of the 20 water years since 2001, our fish surveys ranged from the 1st to the 16th drouthiest years on record (Fig. S1b). The lagoon was open between 2 and 14 d per water year (mean = 5.3, SD = 4.2). We observed 32 d total where the lagoon was open. During the winters of 2015–2017, there were a total of 133 d during the wet season, split across several distinct periods, for which no photo data were available; however, our direct observations identified at least one breaching event during each of those periods. It is therefore possible (but not certain) that the counts of days open in the winters of 2015–2017 are slightly underestimated. The log-transformed

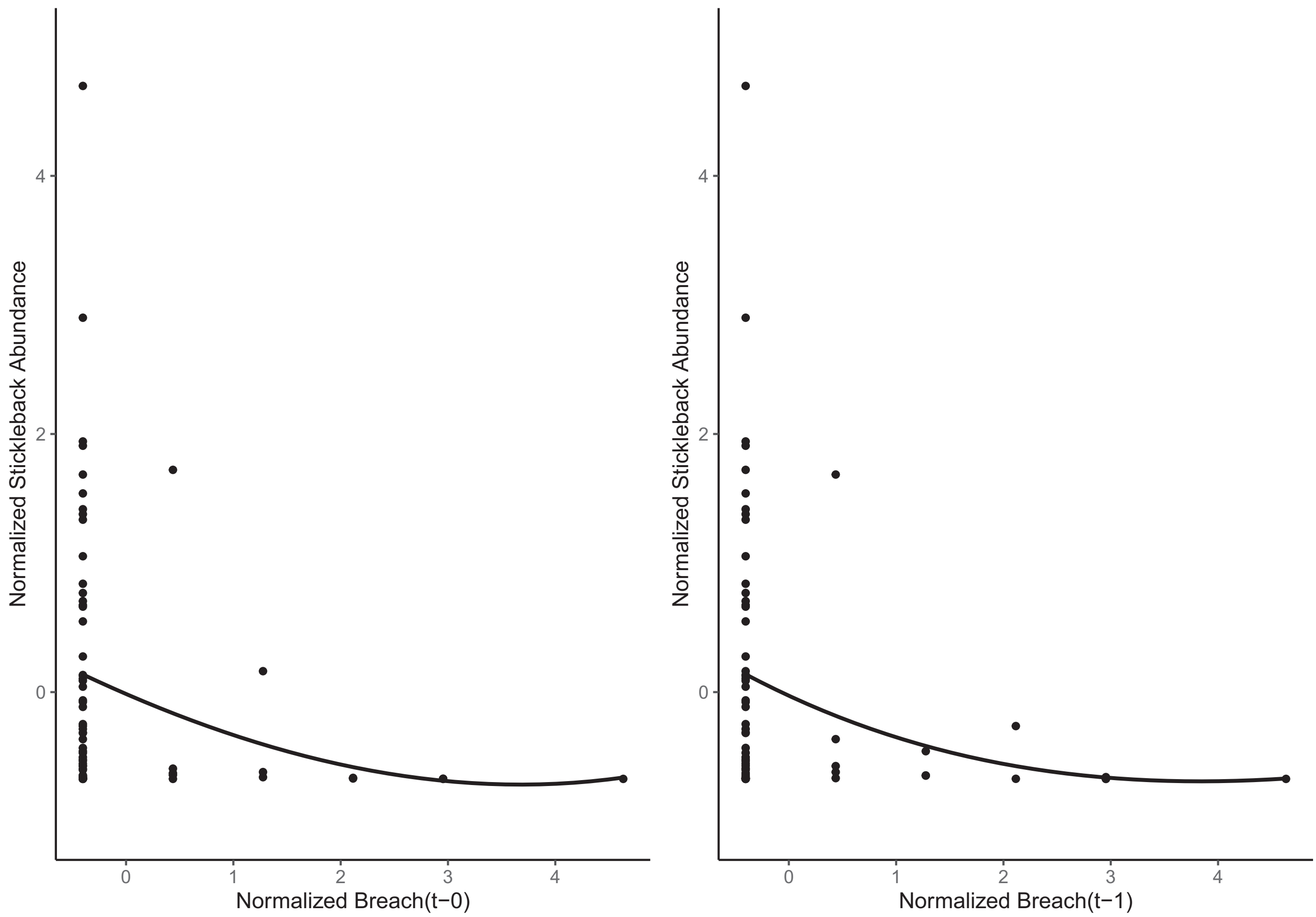

Fig. 3. Normalized stickleback catch per unit effort vs. normalized number of days open (Breach) (**a**) at the same time step, and (**b**) at the previous time step. Lines are LOESS smoothing curves to help visualization, they are not outputs of the convergent cross-mapping model.

Table 2. Time-averaged s-map coefficients for the best model for (a) stickleback (TSS), and (b) Tidewater goby (TWG).

(a) TSS		(b) TWG	
Predictor	Coefficient	Predictor	Coefficient
s_t	0.16	s_t	1.83
s_{t-3}	0.30	s_{t-3}	2.33
Breach_t	−0.06	TSS_{t-2}	−0.12
TSS_t	0.86	TSS_{t-3}	4.86
TWG_t	−0.08	TWG_{t-3}	−0.07

total numbers of days the lagoon breached in a water year was more closely related to rainfall within a year than to Accumulated Drought Severity and Coverage Index which measures cumulative drought conditions (Table 1, Fig. S2). Therefore, breaching is largely a function of within-year conditions rather than multiyear droughts.

Drivers of fish abundance

In general, stickleback were more predictable than gobies. The optimal simplex univariate embedding dimension for stickleback was 2, with $R^2 = 0.21$, while the optimal embedding dimension for tidewater gobies was 4, with $R^2 = 0.03$. We found one significant predictor for each species using convergent cross mapping (CCM). Breaching was the only significant predictor of stickleback abundance (CCM, $p = 0.002$) (Fig. 2a). Stickleback abundance was negatively related to the first two lags of breaching (Fig. 3). Stickleback abundance was the only significant predictor of tidewater goby abundance (CCM, $p = 0.025$) (Fig. 2b). Tidewater goby abundance was positively correlated with stickleback abundance.

Drivers of interaction strength

Effects on stickleback

The best model for predicting the abundance of stickleback at time $t + 1$ included the seasonal predictors and the current time points of stickleback (TSS_t), tidewater goby (TWG_t), and breach (Breach_t), but no time lags from further back. This model had an R^2 of 0.28, slightly better than the univariate stickleback model. The optimal value for θ, the nonlinear tuning parameter, in this model was 0.1 and this means that the model was weakly nonlinear, that is, interaction strengths did not change much as a function of ecosystem state. The mean magnitudes of the coefficient for the effect of tidewater goby abundance and breaching on stickleback abundance were similar and slightly negative; they were smaller than the coefficients for either seasonal predictor or stickleback abundance itself (Table 2).

Even though seasonal variables were included as predictors in the s-map projections, the coefficient for the effect of gobies on stickleback was primarily associated with season, s_t, (ANOVA, $F_{1,59} = 12.75$, $p = 0.001$), and tidewater goby abundance (ANOVA, $F_{1,59} = 6.22$, $p < 0.016$) (Table 3). The interaction strength of tidewater gobies on stickleback was highest

Table 3. ANOVA tables testing for the effects of environmental predictors on the interaction strengths recovered from the multivariate s-map projections. Predictors include seasonal sine functions, monthly rainfall, number of days open (Breach), temperature, salinity, dissolved oxygen (DO), and the abundance of threespine stickleback (TSS), and tidewater goby (TWG).

Response	Predictor	Sum Sq	Df	*F*-value	*p*
$d\text{TSS}_t/d\text{TWG}_t$	SeasonalSine_t	0.040	1	12.753	0.001*
	$\text{SeasonalSine}_{t-3}$	0.001	1	0.267	0.607
	Rain_t	0.007	1	2.074	0.155
	Breach_t	<0.001	1	0.07	0.792
	Temp_t	0.005	1	1.617	0.208
	Salinity_t	0.005	1	1.466	0.231
	DO_t	0.001	1	0.252	0.617
	TSS_t	0.001	1	0.237	0.628
	TWG_t	0.019	1	6.217	0.016*
	Residuals	0.184	59		
$d\text{TSS}_t/d\text{Breach}_t$	SeasonalSine_t	0.003	1	7.479	0.008*
	$\text{SeasonalSine}_{t-3}$	0.001	1	3.633	0.062
	Rain_t	<0.001	1	0.868	0.355
	Breach_t	<0.001	1	0.030	0.864
	Temp_t	<0.001	1	0.007	0.934
	Salinity_t	0.001	1	2.541	0.116
	DO_t	<0.001	1	0.628	0.431
	TSS_t	0.002	1	4.141	0.046*
	TWG_t	0.001	1	3.381	0.071
	Residuals	0.023	59		
$d\text{TWG}_t/d\text{TSS}_{t-2}$	SeasonalSine_t	41.8	1	0.312	0.578
	$\text{SeasonalSine}_{t-3}$	118.7	1	0.886	0.350
	Rain_t	22.9	1	0.171	0.681
	Breach_t	10.9	1	0.081	0.777
	Temp_t	110.4	1	0.825	0.367
	Salinity_t	0.9	1	0.007	0.936
	DO_t	9.7	1	0.073	0.789
	Residuals	8169.3	61		
$d\text{TWG}_t/d\text{TSS}_{t-3}$	SeasonalSine_t	0.6	1	0.005	0.947
	$\text{SeasonalSine}_{t-3}$	822.5	1	6.679	0.012*
	Rain_t	6.2	1	0.05	0.824
	Breach_t	<0.1	1	<0.001	0.988
	Temp_t	1	1	0.008	0.929
	Salinity_t	8.1	1	0.066	0.798
	DO_t	0.7	1	0.006	0.939
	Residuals	7511.6	61		

*Statistical significance ($p < 0.05$).

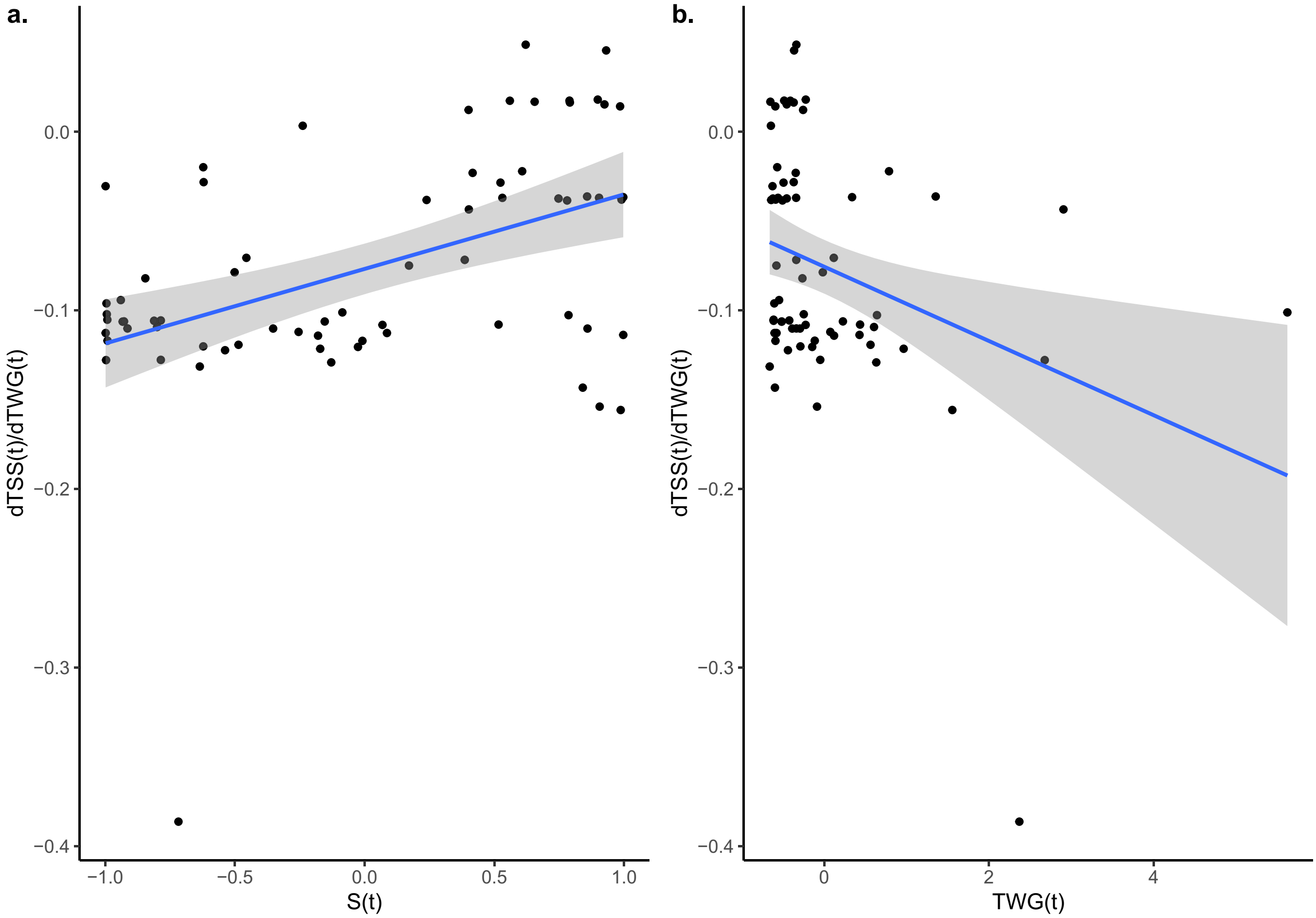

Fig. 4. Effect of tidewater gobies on stickleback (dTSS$_t$/dTWG$_t$) as a function of (**a**) season s_t (minimized in mid-September and maximized in mid-March), and (**b**) tidewater goby density (TWG$_t$).

(least negative) in March and when tidewater goby abundance was highest (Fig. 4).

Effects on tidewater goby

The best model for predicting the abundance of tidewater goby at time $t + 1$ included the seasonal predictors, the second and third lags of stickleback (TSS$_{t-2}$ and TSS$_{t-3}$), and the first lag of tidewater goby (TWG$_{t-1}$). This model had an R^2 of 0.13, considerably better than the univariate model for tidewater goby. The tidewater goby model was highly nonlinear, optimal $\theta = 13.8$, meaning that interaction strengths change as a function of system state.

The largest mean coefficient in the model was for the third lag of stickleback abundance (Table 2). The only significant predictor of this coefficient was season, s_{t-3} (ANOVA, $F_{1,61} = 6.68$, $p = 0.012$). During June and July $d\mathrm{TWG}_t/d\mathrm{TSS}_{t-3}$ had a large positive value, whereas during other times of the year the value was close to zero, usually slightly negative (Fig. 5). There were no significant predictors for the coefficient for the second lag of stickleback abundance ($d\mathrm{TWG}_t/d\mathrm{TSS}_{t-2}$) (Table 3).

Discussion

Our results support the hypothesis that fluctuations in stickleback and endangered tidewater goby abundance reflect independent responses to environmental fluctuations rather than the effects of interspecific competition. Stickleback abundance was negatively affected by sandbar breaching. Tidewater goby abundance was affected by TSS abundance. However, when we used s-map regression to investigate the nature of that relationship, we found that the pattern was primarily driven by a large positive coefficient for the effect of stickleback abundance in the spring on tidewater goby abundance in the summer, rather than by fluctuations in the magnitude of negative interaction strengths that we would expect if state-dependent competition was occurring.

Although prior experiments have indicated the potential for competition (Chase et al. 2016; Chase and Todgham 2016) and the dynamics of population fluctuations in our study system seem to imply competition, our analyses revealed little evidence of competition. In our best model for explaining variation in goby abundance, positive effects of the third lag of stickleback ($dTWG_t/TSS_{t-3}$) outweighed the negative effect of the second lag of stickleback ($dTWG_t/dTSS_{t-2}$), and so the overall mean effect of stickleback on goby was positive (Table 2). Conversely, the mean effect of gobies on stickleback ($dTSS_t/dTWG_t$) was negative, but had a very small magnitude, smaller than either seasonal effects or the effects of lagged stickleback abundance. Therefore, tidewater goby abundance did not have a major impact on stickleback abundance (also see Fig. 2). Taken at face value, this suggests a commensalism whereby stickleback have a positive effect on gobies, but we do not know of a plausible mechanism by which this would occur.

Using s-map regression we investigated the temporal variation in interaction strength to better understand the relationship between the two species. Compared to the small effect of gobies on stickleback, stickleback were the primary driver of goby abundance in our models. For most of the year the magnitude of the effect was quite small. However, counter to our expectations, during the time periods when that effect was large, the effect was positive: in June and July, the lagged effect of stickleback on gobies was positive and very large ($dTWG_t/dTSS_{t-3}$) (Fig. 5). Therefore, for most of the year, there is not much meaningful effect of stickleback on gobies in either direction, but in these 2 months there is a distinct, but lagged, positive effect of stickleback. The lagged effect corresponds to a positive correlation between the abundance of stickleback in March and April with the abundance of gobies in June and July. When stickleback have a good spring, gobies are predicted to have a good summer.

Most likely, this reflects the season when juveniles of each species recruit to a size large enough to be caught in our traps and it may point toward the mechanisms for coexistence of these two species that share a resource base. Perhaps then, stickleback and gobies are responding similarly to an unmeasured environmental driver, such as the onset of spring productivity and availability of shared macroinvertebrate prey, but stickleback respond earlier or more quickly. The major reproductive period of the two species appear to be offset, so

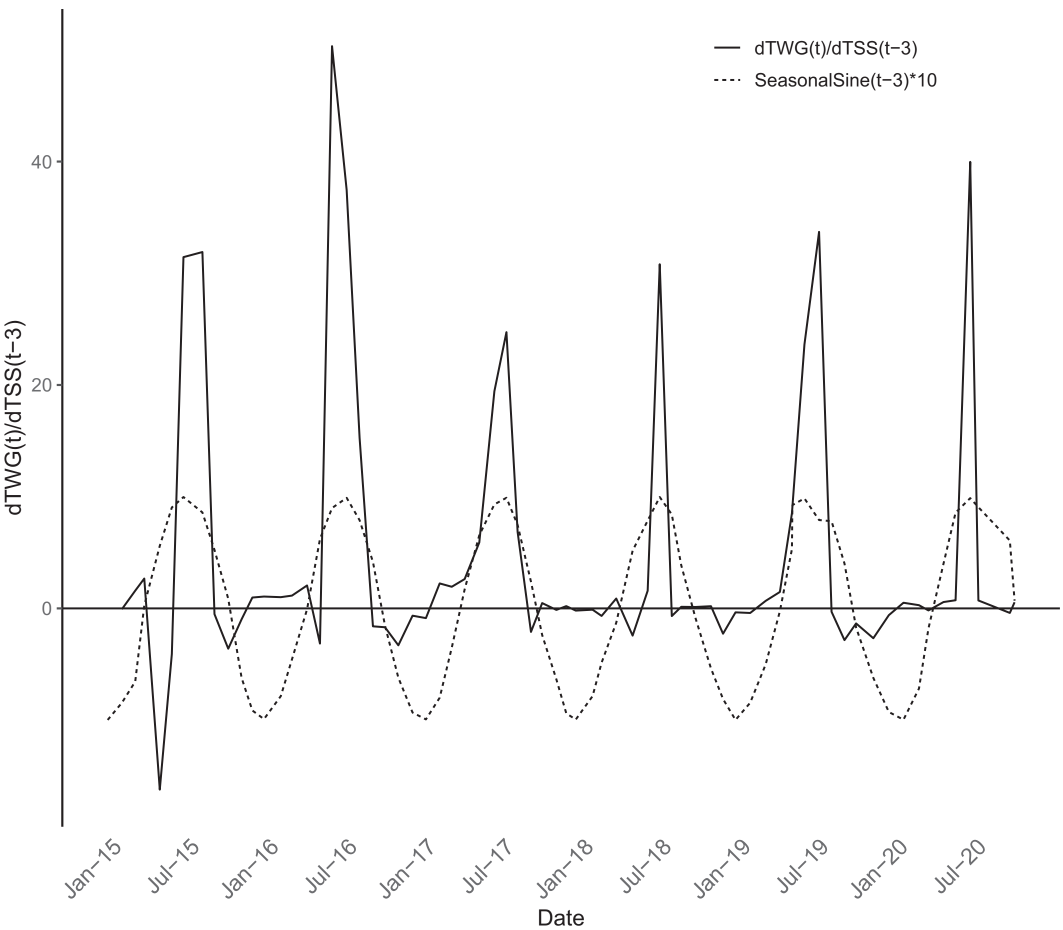

Fig. 5. Effect of stickleback on tidewater gobies ($dTWG_t/dTSS_{t-3}$ solid line) over time compared to the seasonal variable (s_{t-3}, dashed line) over time for the best multivariate s-map model of tidewater goby. Note the magnitude of the seasonal variable is increased 10-fold to aid in ease of interpretation.

niche partitioning may be achieved across seasons (for data on annual cohort timing in nearby lagoons, *see* Swenson 1999 for gobies and Wasserman et al. 2021 for stickleback). Such allochrony has been shown to help limit the potential for competition by offsetting peak resource use (Trivelpiece et al. 1987; Spilseth and Simenstad 2011; Clewlow et al. 2019). Another study of a bar-built estuary food web suggests a similar mechanism at play. Young et al. (2022) found stickleback and prickly sculpin to have a greater overlap in diet and stable isotope niche during the summer than the spring; tidewater goby were also similar during the summer but no goby data were available from the spring. Spatial segregation of resource use could also lead to a lack of negative impacts of the two species, but that does not explain the temporal pattern of positive interactions we detected.

There was a great deal of spatial variation in conditions in Younger Lagoon, just as there was a great deal of temporal variation. We chose to focus on the temporal variation averaged over the spatial variation in this study. This allows us to focus on population- and system-wide data and processes. Our method of attractor reconstruction assumes that measured fish abundance acts as an observation function of the true state of abundance in the population; as long as catch (averaged over all 12 traps) is a monotonically increasing function of true abundance, our attractor reconstructions should give accurate results (Takens 1981). Still, it is possible that the two species might use the habitat differently during different periods of the year when those environmental conditions change (Moyle 2002). For example, we moved our traps around the lagoon to avoid locations where diel oxygen swings may cause fish mortality, but this may have changed the relative accessibility of our traps to stickleback and more anoxia-tolerant gobies (Swift et al. 2018). Unfortunately, this confounding effect could drive some of the relationships we see in the data. Further research could compare trapping studies to other methods, such as contemporaneous seine surveys or trap placement controls to further investigate this source of bias.

An important direct effect of the environment we detected was a negative effect of breaching on stickleback abundance. Breaching appears to be a major mortality event for stickleback, with 90% or more reduction in abundance following the first breach in most years (Figs. 1a, 3). Goby abundance was not impacted by breaching in the same way (Fig. 1b). Although goby mortality in response to artificial, out-of-season breaches has been documented, our data reaffirm that natural breaching is not a major source of mortality for gobies and that they are well adapted to this feature of the environment (Swift et al. 2018). When we observed fish mortality following breaches, the majority of fish stranded on dewatered mud or sand flats were stickleback, and the few tidewater goby observed were alive, and many were on a section of mudflat that would likely rewater at the next high tide (B. A. Wasserman pers. obs.).

All of our models did a better job of predicting stickleback abundance than they did tidewater goby abundance including univariate Simplex, bivariate convergent cross-mapping, and multivariate S-Map. Our analyses are robust to measurement error because time-delay embedding allows us to use data from multiple time points (Munch et al. 2020). However, measurement error or process error (stochasticity) may provide an upper limit on prediction accuracy in empirical dynamic modeling. It is therefore possible that tidewater goby abundance is marked by more stochasticity than stickleback abundance in this system. In addition, there may be other, rarer effects that we were unable to detect because they did not happen during our time series, or only happened on a single occasion. Empirical dynamic modeling generally require a time series that includes enough data to cover several times the characteristic return time for the system to resolve the attractor in that area of parameter space (Munch et al. 2020). For example, in 2018 we witnessed the largest abundances of both stickleback and gobies, followed by a population crash and an apparent wave overtopping event with unseasonable temperature and salinity measurements. The following spring tidewater goby abundances were higher than in other years. One might conclude this was due to lack of stickleback presence. While the Smap coefficients were slightly more negative in that year than others, our ANOVA did not identify any proximate driver of that difference, instead it only detected the overwhelming effect of season on the Smap coefficient of stickleback on gobies.

The conclusion that stickleback and goby are not influencing each other's population abundance, but rather responding separately to environmental fluctuations will be important for the management of these species. However, they co-occur in a variety of environments and these results will be most applicable to similar ecosystems. Small bar-built estuaries draining intermittent streams in central California share a number of features that may influence this interaction. In such small sites that are rarely flowing, the submerged aquatic plant *Ruppia* is common in some summers. Predatory fishes are not present in Younger Lagoon and similar sites, but are found in many other estuaries draining larger watersheds where stickleback and goby co-occur (Wasserman et al. 2020). Many other elements of the ecosystem and community change along the north–south axis of the tidewater goby's range that might impact this interaction, such as climate and the presence of other species (des Roches et al. 2020).

Empirical dynamic modeling has been used to make predictions and infer causality, and it is now starting to be used to improve forecasting of commercially valuable fish stocks (Anderson et al. 2008; Ye et al. 2015; Giron-Nava et al. 2020) and to answer questions in community ecology such as determining the effect of biodiversity on stability and the drivers of bottom-up and top-down effects (Sugihara et al. 2012; Ushio et al. 2018; Rogers et al. 2020). As opposed to computing such community-wide metrics, our goal was to understand the environmental factors that affect a particular species of conservation concern and its interspecific interactions (Deyle et al. 2016a). We think there is a real opportunity in using these methods for such studies when monitoring data are available but manipulative experiments are impractical, whether that be for cost, logistical, or ethical reasons.

We used empirical dynamic modeling to understand the interaction between two putative competitors in a seasonally fluctuating environment. We showed fluctuations in interaction strength but rarely showed competition. Instead, our data revealed that seasonal cycles of both species reflect their unique responses to environmental conditions including annual pulses of recruitment that were offset by approximately 3 months. Empirical dynamic modeling can be used to understand the context dependence in interactions, especially in cases like ours utilizing endangered species, when the usual methods (manipulative experiments) are not an option. Our method allows us to understand the drivers of variation in abundance of the endangered goby and strongly suggests against competition from TSS as a threat to goby population numbers. This information can be used to make decisions about the management of the focal species. We suggest that restoration of bar-built estuaries should take precedence over efforts to eliminate the interaction with stickleback (Zedler 1996; Clark and O'Connor 2019). Similarly, empirical dynamic modeling can be used to decide between alternative conservation actions in other cases.

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Conflict of interest

None declared.

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