*Study Area*

This study was conducted on and around the University of California Santa Barbara in Santa Barbara County, California USA. The study area lies within one mile or less of the Pacific Ocean, and therefore enjoys a Mediterranean climate that can be generalized as cool and wet during the months of October – April, and warm and dry during the months of May- September. Rainfall averages approximately 17 inches per year with notable variation often exacerbated by extreme rainfall events and droughts. (CITATION). The close proximity to the Pacific moderates winter lows and frost is relatively rare along the coast and does not persist. Summer fog likewise moderates summer temperatures although offshore Santa Ana winds may bring hot dry conditions over 90F to the area especially in the late summer and fall. The soils are typically clayey and the project site’s topsoils were scraped in the 1960’s, leaving clay soils that are typically high in sodium and low in organic material and nitrogen.

*Restored Vernal Pools*

All vernal pool restoration was conducted at the University of California Santa Barbara by the Cheadle Center for Biodiversity and Ecological Restoration (CCBER). Starting in 2016, we began monitoring 7 restored vernal pools within the North Parcel restoration area (Figure 1). Restoration of these communities consisted of grading to deepen vernal wetland basins and improve hydrologic conveyance. To facilitate soil restoration, sifted compost from the Santa Barbara County was distributed across the upland areas of the site at approximately 6 inches in depth. This was then incorporated with a tractor while the soils were dry to a depth of approximately 8-10 inches. No organic material was incorporated into the wetland basins. Additionally, a humate product called Live Earth Soil Conditioner (1.50% sulfur, 2.25% iron, 45% humic acid) and Live Earth First Green (4% calcium, 5% sulfur, 1% iron, and 5% nitrogen, 3% phosphorous, and 1% potassium) was equally distributed one time, across both wetland and upland soils, at a rate of approximately (need amount). The project sites were then planted, and to a lesser degree seeded with approximately 140 species of locally-sourced native plants from vernal pool, vernal marsh, coastal prairie, and coastal sage scrub communities. Most plants were installed on 1 ft centers, with coastal scrub plantings averaging one plant per 3 ft center. The project’s scope included an installation phase of 5 years with a limited maintenance budget thereafter. Weeds were controlled mainly by hand-weeding, although also through solarization, herbicide, and green flaming. Installed plantings were watered-in using mainly moveable drip irrigation until establishment was achieved. Planting continued throughout the summer months in some cases. Thatch from a number of native annuals has been removed seasonally as feasible in the late summer and fall months, to facilitate the clearing done by indigenous burning and create new opportunities for germination and avoid the thatched-over landscapes that inevitably occur without burning or other disturbances in a semi-arid region where vegetation is slow to decompose. These include species such as Centromadia parryi australis, Simphyotrichium sublatum, Dienandra fasciculata, for example. In addition, the thatch material from perennial natives, such as Stipa pulchra, is also removed annually in places for the same effect. Vegetation was purposely planted in patches such as those that are generally observed in nature, according to soil types, hydrology, and other factors. Certain natives are removed periodically to maintain landscape variability, facilitate the colonization of novel or desirable native species, and avoid homogenization of common species such as Baccharis pilularis, Typha sp., Schoenoplectus californicus, and Salix sp.

*Experimental Design*

Exotic Species Monitoring

Within each restored vernal pool we set up a series of monitoring quadrats to assess how abiotic and biotic characteristics of the site influences invasion rates by exotic species. Within each vernal pool, we delineated the habitat into three zones: a *central zone* that is fully inundated during the winter rainy months, a *transition zone* that is never inundated but experiences continually wet soils throughout the winter rainy season, and an *upland zone* that only receives water from precipitation events and does not receive additional water from the vernal pool (Figure 2). Within each of these zones (central, transition, and upland) we haphazardly placed three 1m2 quadrats.

Seed Bank Sampling

In October of 2016, prior to the first rain event of the year, we sampled the seed bank haphazardly at a depth of 5cm 3 times in each quadrat. All soil cores taken within each quadrat were consolidated so that there was one seed bank sample per quadrat. Prior to sowing, all soil samples were homogenized and 25g was subsampled. All soil samples were then thinly spread over a tray filled with 5cm of #4 sunshine potting mix and watered thoroughly in the nursery.

Plant Community Monitoring

The plant communities in all vernal pools (both restored and reference pools) were monitored annually. Two transects were laid across each vernal pool with one transect cover the long diameter of the pool and the other covering the short diameter of the pool (Figure 3). The identity and percent cover of all species was recorded.

*Data Collection*

Field Quadrat Monitoring

Starting in November 2016, we monitored the plant communities in each vernal pool monthly. Within each quadrat we assessed the identity and percent cover of all species present. For native species, in addition to percent cover we estimated the number and percent cover of germinating seedlings. For exotic species, we destructively sampled all exotic species and measured the above ground biomass for each species.

Seed Bank Analysis

Starting one week after the soil cores were sowed, we monitored the trays weekly for new germination. After identification, all species were harvested to prevent shading of other germinating seeds. After two weeks with no new germination had passed monitoring ceased.

6 pools made in different yrs

Original seed bank

Vegetation monitoring

2 yrs of monthly data – continuous monitoring – monthly b/c Wayne wants to get rid of the weeds and doesn’t want to let them seed

DON’T WEED PLOTS but also manage as you would the rest of the land -- If you’re going to weedwack everything, then weedwack the pools, but don’t just weed invasives

Interested in effort – weeding effort

Look at what seeds are in seedbank vs what seeds are coming up 🡪 if weeds are from seeds or blowing in

Effort in relation to native species diversity or cover

At some point, pools go into maintenance mode 🡪 what happens when you get to maintenance mode (converge on a certain community)

Wayne really wants to publish NP and see how well he’s managing the land

After 3 yrs post-restoration, where are you at? Do you just have a level of weeds? How much active management is needed?

Restoration success vs realities of how we actually do restoration – time and money limited

CCBER budget – lots of funding for 5 yrs, then funding is cut to maintenance level

Could expand to other sites

Andy in charge of Manzanita (older, heavier use) – would be super interesting to see what diff animal communities are in SP vs NP vs Manzanita

Beau/Darwin in charge of SP

You just have to make sure that the plots aren’t being weeded -- easy at NP with Wayne and Cat on board

Del Sol Vernal pools in front of NCOS off El Colegio (Isla Vista parks – CCBER does monitoring for them) – may allow you to input new genotypes

San Clemente (on El Colegio/Los Carneros) – don’t have “local only” rule

The hard part is communicating with everyone about your plots and how to avoid them/not weed there (Cat, Johnny, Steven, Beau, Chris…) – probably won’t care if you experiment on the land, but won’t pay you

Intro new plants – even if you herbicide, you get pollen contamination 🡪 intro new plants that don’t exist on site & then you can remove them completely

Ellwood Mesa fenced off VP on the side of cliff trail, find VP out of reserves (Nicole in FS)

Email Cat 🡪 get permission from Lisa 🡪 talk to site supervisors

# hours work (work effort) spent, species list (what was planted, direct seeded, vs what has come in naturally) (handwritten workbooks – ask Cat), info about VP (size, soils)

Lisa – need to know more about VP construction – were they constructed w/ different techniques, diff grading, diff inoculum, diff management, diff current effort, etc; info about VP (size, soils, what was planted, direct seeded, etc), ask about Kelly for Storke VP data

2018 Methods

Seed Bank Analysis

Soil cores were taken from each quadrat in November 2018. Soil was taken 5cm down, as in 2016. Three cores were taken from each quadrat, then combined into one sample per quadrat. Two additional samples were also taken outside of quadrats in the transition and upland zones (three cores each, taken within a 1m2 area) to evaluate the seed bank under CCBER’s weed management regime. Soil cores were also taken from haphazardly placed quadrats at four Del Sol pools: nine samples per pool (three cores each, 8cm deep), three samples in each zone. On November 30, 2018, soil cores were sowed in trays: 25g of soil from each sample was sowed atop sunshine #5 potting mix. Trays were watered to keep the soil moist. (On December 6, an additional replicate of PH1 samples were sown into trays using 50g of soil per sample.)

GPS Points of Del Sol Samples 2018

|  |  |  |  |
| --- | --- | --- | --- |
| Pool | Replicate | Lat | Long |
| S | C1 | 24.9874 | 51.9016 |
| S | C2 | 24.9869 | 51.9035 |
| S | C3 | 24.9845 | 51.9035 |
| S | T1 | 24.9833 | 51.8986 |
| S | T2 | 24.9876 | 51.8979 |
| S | T3 | 24.9873 | 51.9080 |
| S | U1 | 24.9840 | 51.9057 |
| S | U2 | 24.9886 | 51.8962 |
| S | U3 | 24.9898 | 51.9051 |
| H | C1 | 25.0120 | 51.8915 |
| H | C2 | 25.0126 | 51.8913 |
| H | C3 | 25.0123 | 51.8923 |
| H | T1 | 25.0144 | 51.8928 |
| H | T2 | 25.1234 | 51.8900 |
| H | T3 | 25.0120 | 51.8911 |
| H | U1 | 25.0115 | 51.8893 |
| H | U2 | 25.0103 | 51.8939 |
| H | U3 | 25.0150 | 51.8933 |
| J | C1 | 25.01310 | 51.9100 |
| J | C2 | 25.0127 | 51.9108 |
| J | C3 | 25.0144 | 51.9103 |
| J | T1 | 25.0125 | 51.9116 |
| J | T2 | 25.0145 | 51.9115 |
| J | T3 | 25.0127 | 51.9088 |
| J | U1 | 25.0115 | 51.9071 |
| J | U2 | 25.0111 | 51.9111 |
| J | U3 | 25.0155 | 51.9124 |
| L | C1 | 25.0051 | 51.9099 |
| L | C2 | 25.0052 | 51.9100 |
| L | C3 | 25.0042 | 51.9101 |
| L | T1 | 25.0042 | 51.9095 |
| L | T2 | 25.0055 | 51.9116 |
| L | T3 | 25.0041 | 51.9103 |
| L | U1 | 25.0054 | 51.9125 |
| L | U2 | 25.0028 | 51.9000 |
| L | U3 | 25.0096 | 51.9053 |

Abstract

Invasive species management in restoration projects is often heavily frontloaded due to long-term budget constraints. Even if these restoration projects show high native species success in the short term, these projects are prone to exotic species invasion when the post-restoration “maintenance phase” of the project is implemented. Restoration of California’s historically uniquely endemic vernal pool ecosystems is facing increasing exotic species invasion exacerbated by global change. We investigated how exotic species abundance and diversity correlates with time since restoration.

Restoration projects with frontloaded short-term invasive species management do not guarantee a restored ecosystem’s long-term resistance to invasion. Long-term budget constraints often result in intensive exotic species weeding effort only 1-3 years after restoration. Even if these restored ecosystems show low exotic species abundance in the short term, these ecosystems may not be resistant to exotic invasion in the long run. Exotic invasion in restored vernal pool ecosystems is of special concern. California’s highly endemic vernal pool ecosystems are facing increased exotic species invasion exacerbated by global change. Vernal pools, which often form within a grassland matrix, are especially prone to invasion by exotic annual grasses. We investigated the dynamics of exotic species abundance and diversity after intensive invasive species management had ceased by measuring species percent cover in a southern coast mitigation site including restored vernal pools. We found that exotic species cover and richness increased after intensive exotic species weeding had ceased. An increase in exotic annual grasses around the vernal pools’ edges indicates encroachment of exotic grasses from the upland grassland into the pools. Further, we found that the ratio of total native species cover to the total exotic species cover decreased around the pool edges. These findings indicate that native communities in restored vernal pools are not resistant to invasion by exotic species. Restoration projects may increase a vernal pool’s resistance to invasion by employing an array of invasive species management techniques in addition to short-term weeding, such as bolstering the native seed bank and sourcing seed from competitive native ecotypes.

CalBotSoc and SERCal Abstract: Exotic Species Invasion in Restored Vernal Pools

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95% of California’s vernal pool ecosystems have been lost, resulting in a growing effort to restore these ecosystems and their associated endemic flora and fauna. However, because restored vernal pools often exist within a grassland matrix, they are prone to invasion by exotic annual grasses. We hypothesize that restored vernal pools are particularly susceptible to exotic invasion because restoration projects often have frontloaded short-term invasive species management. Long-term budget constraints often result in intensive exotic species weeding effort only 1-3 years after restoration. Even if these restored ecosystems show low exotic species abundance in the short term, they may not be resistant to exotic invasion in the long run.

We assessed exotic species abundance and diversity after intensive weeding had ceased in a set of restored vernal pools in Southern California. We found that exotic species cover and richness increased, particularly around the edges of the pools. We hypothesize that this increase in exotics around the pools’ edges indicates encroachment of exotic grasses from the upland grassland into the pools. Further, we found that the ratio of total native cover to total exotic cover decreased around the pool edges. These findings indicate that the native communities in our study’s restored vernal pools are not resistant to exotic invasion. One way that restoration projects may increase a vernal pool’s resistance to invasion is by employing an array of invasive species management techniques in addition to short-term weeding, such as bolstering the native seed bank and sourcing seed from competitive native ecotypes.

Cal-IPC Abstract: **Effects of abiotic and biotic constraints on invasion in restored vernal pools**

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95% of California’s vernal pool ecosystems have been lost, resulting in a growing effort to restore these ecosystems and their associated endemic flora and fauna. However, because restored vernal pools often exist within a grassland matrix, they are prone to invasion by exotic annual grasses. We hypothesize that restored vernal pools are particularly susceptible to exotic invasion because restoration projects often have frontloaded short-term invasive species management. Long-term budget limitations often result in the application of biotic constraints, i.e. intensive weeding, only 1-3 years after restoration. Abiotic site conditions are also manipulated upfront, with created pools having deeper topography to impose the abiotic constraint of longer inundation periods in order to preclude exotics. However, these abiotic and biotic constraints may not be sufficient in restricting exotic invasion in the long run.

We assessed species abundance and diversity after intensive weeding had ceased in a set of restored vernal pools in southern California. We found that the depth of the pool did not significantly affect the total exotic cover and richness. Instead, we found that the exotic species cover and richness increased over time, particularly around the edges of the pools. Further, we found that the ratio of total native cover to total exotic cover decreased around the pool edges. These findings indicate that the native communities in our study’s restored vernal pools are not resistant to exotic invasion, despite the abiotic and biotic constraints imposed on them. We thus propose the employment of other long-term invasive species management strategies, such as annual exotic thatch removal and annual native seed supplements. We propose testing these strategies on our study site pools to determine if they provide effective and cost-efficient management methods for restoration practitioners.

Notes

* Compare seedbank vs current weeds (weedy seedbank vs wind dispersal of spp?)
* Which natives are doing the best? Which nonnatives are forming monocultures?
* Convergence on certain community/amount of nonnatives over time?
* What’s the ideal frequency/duration of monitoring to see unequivocal results?
* Active management vs passive management (compare to old Del Sol data)
* Maybe need to convert count to % in seedbank, then compare to max % cover
* When using biomass data, just add up all biomass per year (don’t average) – you should use total biomass per year per pool
* When we collected seedbank, remember that we’re collecting what’s in the seedbank right before the growing season
* Separate natives by time/phenology? Compare growing season b/t nonnative and natives (for each nonnative, find out % overlap w/ native and find spp w/ strong inverse relationship b/t % cover nonnative vs % cover native)
* May need to take into account interannual climate variability when you’re looking over time (NOAA data)
* Remember: each pool is a replicate – you should have one metric (average) per pool (or per zone per pool) to reduce noise so you can pull out trends
* Try plotting as a time series and fit to exponential linear model and find where the inflection point is = threshold year for when nonnatives increase
  + Remember your points are NOT independent b/c it’s the same plot year after year – make sure your analysis doesn’t assume independence 🡪 repeated measures ANOVA or repeated measures GLM (poisson or negative binomial distribution) or random mixed effects model

How does exotic species abundance and diversity correlate with time since restoration?

* Prediction: increased abundance and diversity with increased time since restoration
* Graphs
  1. boxplot of max % cover of each exotic species, 2017 vs 2018 – BOXPLOT BY POOL NOT SP
  2. boxplot of mean % cover of each exotic species, 2017 vs 2018

Do the invading exotic species exhibit a similar set of traits?

* Possible groupings:
  1. By pool
  2. Central zone vs. transition zone vs. upland zone species
  3. Annual vs. perennial
  4. Present in seed bank
  5. Mismatching phenology from natives (some index of germination ease or phenology)
  6. Moisture regime
  7. Max height (index of competition)
* Graphs
  1. same 2 graphs, facet wrapped by pool
  2. same 2 graphs, facet wrapped by zone; Native vs invasive line graphs of c to t to u
  3. Annual vs perennial graphs of c to t to u
  4. Max % cover vs % in seed bank
  5. Comparing growing season b/t exotics and natives - for each exotic species, find out % overlap with native (% cover exotic vs % cover native) 🡪 pick out species where there's a strong inverse relationship b/t % cover exotic vs % cover native
  6. POMO and FEPE like moisture

NP Draft 6 (np\_draft6\_Rmd)

**Q1**: Is sustained weeding effort successful?

H1: If sustained weeding (routine weed-whacking, monthly hand-weeding) is successful, exotic cover will remain low.

🡪 If not, then what’s the mechanism allowing exotics to proliferate? Weeds blowing in from surrounding invaded matrix

🡪 Effort in relation to diversity/cover

🡪 Diversity/cover over time = BOXPLOT/COLUMN GRAPHS OF MAX EXOTIC % COVER AND BIOMASS (a), DIVERSITY (b) OF EACH POOL/ZONE: EVEN W/ CONSTANT WEEDING, EXOTICS STILL INCREASE OVER TIME (EVEN THOUGH NATIVES ARE STABLE) 🡪 **would you say the exotics are invading open niches?** (b/c natives are still there, but are natives missing functional groups that allow invaders to come into open niches due to niche complementarity?

H2: If “maintenance mode” is successful in the long run, exotic cover will remain low and native cover will remain high.

🡪 If not, then when is the threshold of exotic increase/native decrease?

🡪 After 3 yrs post-restoration, where are you at? Do you just have a level of weeds? How much active management is needed? 🡪 can compare to Del Sol (passive management) = NMDS OF ALL POOLS (AND DEL SOL) TO SEE IF THEY’RE CONVERGING ON ONE COMMUNITY (d) (e) (g)

🡪 Which natives are doing the best? Which exotics are forming monocultures, and do these species exhibit a similar set of traits?

**Q2**: Is seedbank different from percent cover monitoring?

H1: If exotic species are coming up in above-ground monitoring that are not found in below-ground seedbank diversity, then seeds are blowing in from surrounding invaded matrix.

H2: If native species are in the seedbank but are not found in above-ground monitoring, then an environmental filter is preventing them from germinating, despite sustained weeding effort.

🡪 NDMS OF SEEDBANK VS PC DATA (PRESENCE/ABSENCE) (a)

**Q4**: How do you measure long-term success?

H1: Monthly monitoring will better capture effects of restoration

H2: Three years of monitoring will better capture effects of restoration

🡪 What’s the ideal frequency/duration of monitoring to see unequivocal results?

🡪 Does your conclusion of success change if you change the resolution/timescale of monitoring? I.e., is the extra monitoring worth it?

FACET BY ZONE – average quadrats in a zone to get one # per zone per pool, per year

NP Draft 7 (np\_draft7.Rmd)

* Q1: Is sustained weeding effort successful?
  + H1a: If sustained weeding (routine weed-whacking, monthly hand-weeding) is successful, exotic cover will remain low. (*alternative H1: If “maintenance mode” is successful in the long run, exotic cover will remain low.*)
    - Discussion point: If not, then what’s the mechanism allowing exotics to proliferate? Weeds blowing in from surrounding invaded matrix
    - Discussion point: Which natives are doing the best? Which exotics are forming monocultures, and do these species exhibit a similar set of traits?
  + 1a: Exotic cover, biomass, diversity over time
    - Boxplot of max annual exotic cover, by zone (GLMER+ANOVA)
    - Boxplot of total exotic biomass, by zone (GLMER+ANOVA)
    - Column graph of exotic H’, by zone (ANOVA)
    - EXOTICS STILL INCREASE OVER TIME 🡪 there’s a threshold crossed at year 4
    - Discussion point: would you say the exotics are invading open niches? (b/c natives are still there, but are natives missing functional groups that allow invaders to come into open niches due to niche complementarity?
  + ~~H1b: Pools that are restored in the same way will converge on the same community over time.~~
  + ~~1b: Whole community~~
    - ~~NMDS – change at age 6: age 2-6 are the same, 7-9 are the same~~
    - ~~Cluster – U kind of clusters out??~~
  + H1c: Exotic annual grass species will consistently dominate the community and outcompete native species.
  + 1c: native community
    - Column graph of max annual native cover, by zone (ANOVA): NATIVES INCREASE OVER TIME (linear model??)
    - Column graph of native H’, by zone (ANOVA): NATIVES INCREASE AROUND 5
    - Find dominant natives/nonnatives
      * dominant exotics: FEPE, FEMY, POMO, CETE, BRDI, GEDI, PLCO, POAN, SPSP, BRHO, CRSC, LYHY
      * dominant natives: ELMA, STPU, JUPH, JUME, HOBR, BOMA, CAPR, CYER, JUBU, ERVA, ALSA, JUPA, MALE, SIBE, CEPA, ELTR, EPCA, ELGL, SCPU, SYSU, DEFA, FRSA
* Q2: How does it compare to passive restoration?
  + Compare to Del Sol 2016 data – but you have to compare using pool as a replicate (diff quadrat sampling methods, no zones for Del Sol data)

Pools

* Generally 15-18cm deep
* Creation date
* Start of maintenance phase
* Depth
* Phase 1
  + 2010
  + Maintenance phase: 2012
  + Max depth: 13
  + 1/25 depth: 13
* Creekside (#19)
  + 2013
  + Shallow; lots of weeding effort
  + Max depth: 13
  + 1/25 depth: 12
* Whitetail 1 (#14)
  + 2014
  + Good – entirely rainfed; steeper & deeper than planned; lots of weeding effort
  + Max depth: 14
  + 1/25 depth: 13
* Whitetail 2 (#16)
  + 2014
  + Receives urban runoff & runoff from pool #13; steeper & deeper than planned; lots of weeding effort
  + Max depth: 16
  + 1/25 depth: 15.5
* Mini South (#9)
  + 2015
  + Receives urban runoff; steep-ish
  + Max depth: 13
  + 1/25 depth: 13
* Tadpole (#7)
  + 2012
  + Deep; less weeding effort
  + Max depth: 18
  + 1/25 depth: 17.75
* Redtail (#3)
  + 2012
  + Shallow & gradual; dries out fast; used to be good, but then infested with Phalaris aquatica & Polypogon monospeliensis
  + Max depth: 13
  + 1/25 depth: 12

Data

* NP\_Monitoring\_Master.xlsx
* NP Weed Biomass