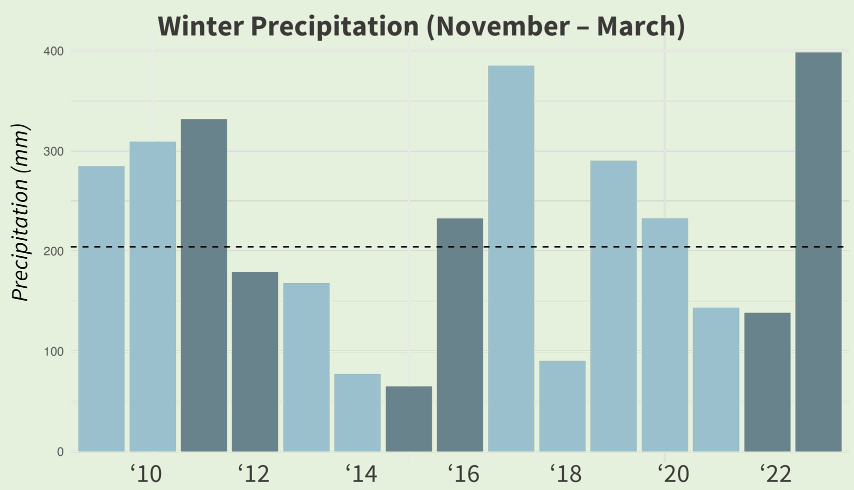
# Variable precipitation and habitat fragmentation jointly impact native bee assemblages

Jessica L. Mullins[1], K. James Hung[2], John S. Ascher[3], David A. Holway[1]

**1.** University of California San Diego, Dept of Ecology, Behavior, and Evolution **2.** University of Oklahoma, Oklahoma Biological Survey **3.** National University of Singapore, Dept of Biological Sciences

## INTRODUCTION

- Insect biodiversity loss is widely reported, but the extent and causes of decline remain debated due to limited long-term data[1].
- Land-use and climate change are the primary drivers of biodiversity loss[2], yet their interaction is poorly understood.
- Coastal San Diego County, California, supports endangered scrub ecosystems with high levels of endemism and diversity[3] and extreme interannual variation in precipitation[4] (Fig 1a).
- Precipitation is a direct correlate of primary production, and thus the key nutrient sources for bees (nectar and pollen).
- Fragmented habitats in San Diego offer a unique chance to examine the combined impacts of land-use and climate change on a biodiverse fauna.



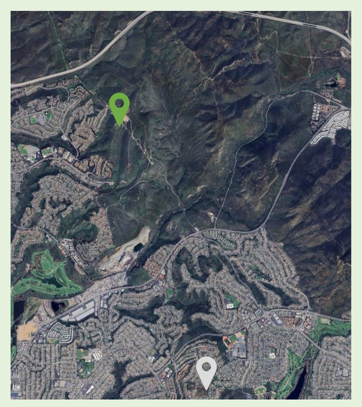



**Fig 1a.** Bar plot of winter precipitation (March – November) from Montgomery Field Airport 2009-2023 provided by NOAA. Dark blue bars depict survey years, dotted line represents 25-year average.
**Fig 1b.** Map of San Diego including one **reserve** and **fragment**. Imagery from Google Earth 2024.

## BACKGROUND

Bee species richness is 31% lower in scrub **fragments** than in **reserves**[5-7]. During drought, species richness is lower than that of non-drought years in **reserves**, but not in **fragments**[8]. This suggests that "bet-hedging" species that can remain dormant during times of drought are extirpated from **fragments**, and only persist in **reserves**.

### This study examines how precipitation variation influences native bee assemblages.

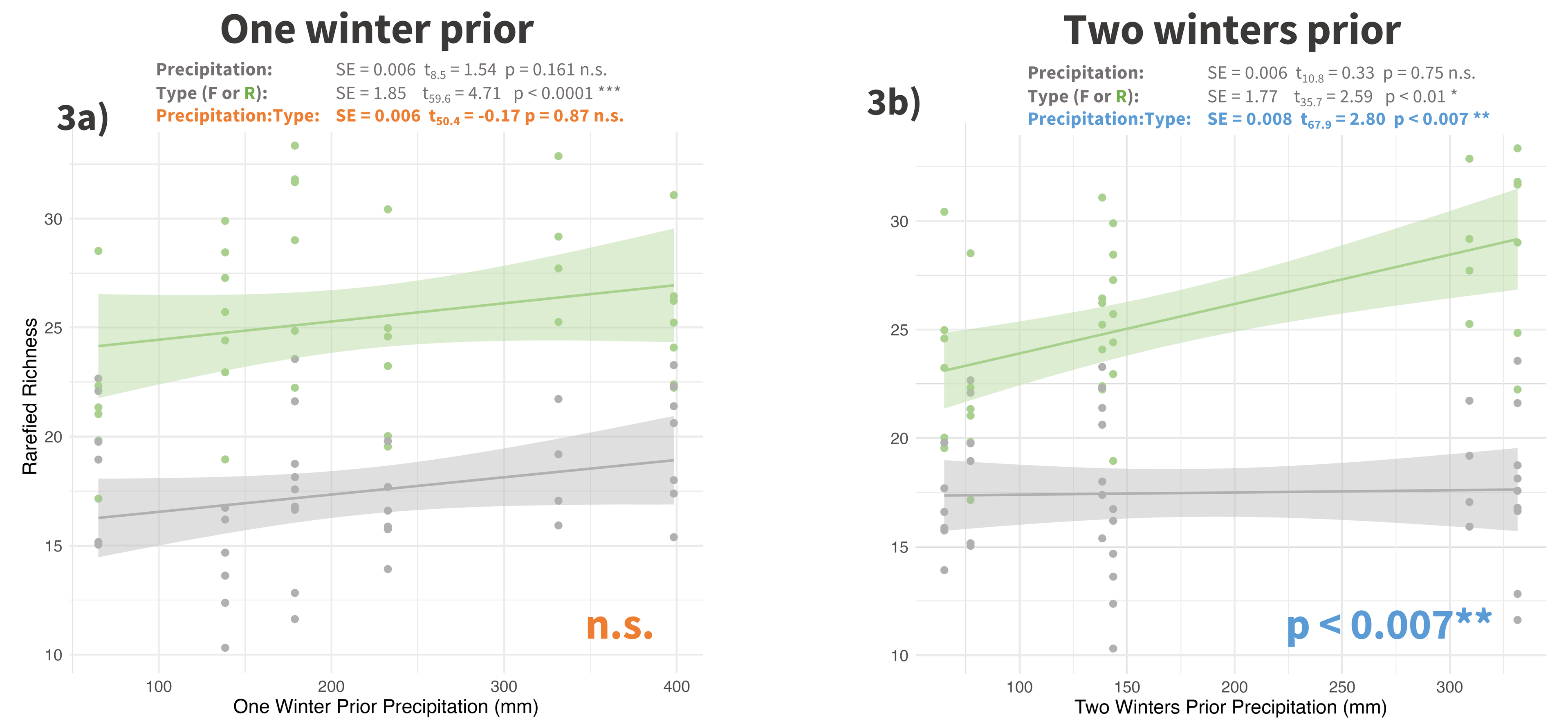
**Figs 2a-c.** Ground-nesting bees provisioning their nests in the spring and summer months. Progeny will be adults in the following spring and summer. From left to right: a. *Halictus ligatus* b. *Diadasia bituberculata,* c. *Trachusa perdita.* Photos by Craig Chaddock.

## HYPOTHESES

**PRECIPITATION TIMING:** If bee assemblages exhibit a delayed response to precipitation, then species richness will be more influenced by precipitation from two years before the flight season than from one year prior.

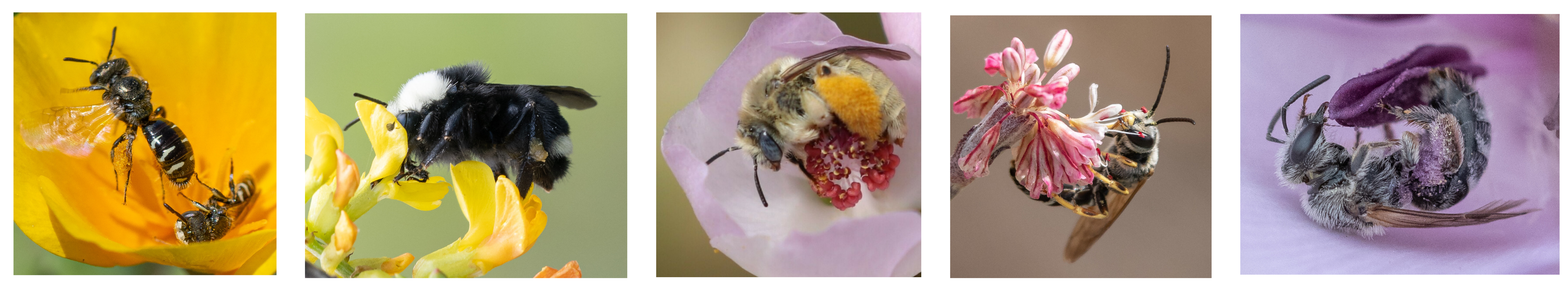
**HABITAT FRAGMENTATION + PRECIPITATION:** Increased precipitation will enhance species richness in **reserves** but not in **fragments**.

## Bee richness responds to precipitation from two winters prior flight season in reserves, not fragments.




**Figs 3a-b.** Linear regressions for native bees collected between 2011-2023 (n = 20,376 of n = 209 morpho species) illustrating the change in rarefied richness in response to the winter precipitation immediately preceding spring – summer surveys (3a), and two winters preceding spring – summer surveys (3b). Each point represents the rarefied richness for a plot in that survey year in two plot types: **reserves** vs. **fragments**. Halos represent standard error. Richness is always higher in **reserves** than in **fragments**, and disproportionately higher in **reserves** that experience a wet winter two years prior (3b).

### 18 indicator species increase after elevated rainfall two winters prior to the survey year.



**Figs 4a-e.** Indicator species from left to right: a. *Perdita interrupta* male and female, b. *Bombus vosnesenskii*, c. *Diadasia ochracea*, d. *Halictus farinosus*, e. *Lasioglossum sisymbrii*. Photos (all but c) by Craig Chaddock, (c) by Cindy Pencek (@thumbwave and @carrotpeople on iNaturalist).

| Family | Species | Sociality | Diet | Nest location | Nest Build | Size (mm) | Value | p-value |
|---|---|---|---|---|---|---|---|---|
| Andrenidae | *Andrena* nr. *ablegata* | S | P | G | E | NA | 0.417 | 0.020* |
| | *Perdita interrupta* | S | O | G | E | 1.2 | 0.461 | 0.010** |
| Apidae | *Bombus californicus* | E | P | G | R | 3.7 | 0.470 | 0.005** |
| | *Bombus vosnesenskii* | E | P | G | R | 3.5 | 0.617 | 0.005** |
| | *Ceratina nanula* | S | P | G | E | 1.1 | 0.687 | 0.005** |
| | *Diadasia bituberculata* | S | O | G | E | 3.4 | 0.698 | 0.005** |
| | *Diadasia ochracea* | S | O | G | E | 2.5 | 0.689 | 0.020* |
| | *Melissodes lupinus* | S | O | G | E | 2.3 | 0.556 | 0.010** |
| | *Melissodes plumosus* | S | O | G | E | 2.3 | 0.659 | 0.005** |
| Halictidae | *Dufourea* aff. *sandhouseae* | S | O | G | E | 1.1 | 0.480 | 0.015* |
| | *Halictus farinosus* | E | P | G | E | 2.2 | 0.861 | 0.005** |
| | *Halictus ligatus* | E | P | G | E | 2.3 | 0.646 | 0.005** |
| | *Lasioglossum* cf. *robustum* | E | P | G | E | 2.0 | 0.590 | 0.005** |
| | *Lasioglossum sisymbrii* | S | P | G | E | 1.9 | 0.702 | 0.005** |
| | *Lasioglossum (Dialictus)* sp. 1 | E | P | G | E | 1.1 | 0.596 | 0.005** |
| Megachilidae | *Megachile* cf. *seducta* | S | O | F | R | 2.9 | 0.417 | 0.010* |
| | *Osmia clarescens* | S | P | C | R | 2.6 | 0.432 | 0.015* |

**Table 1.** Eighteen species that positively respond to precipitation two winters before their flight season. Life history traits from Hung *et al.* 2019[6]. Traits: Sociality: S = Solitary, E = Eusocial; Diet: P = polylectic, O = oligolectic; Nest location: G = underground, Nest build: R = Rent, E = Excavate, Size = Inter-tegular distance in mm. Years classified as "high" precipitation from two winters prior are 2011 and 2012. No indicator species were detected in response to a wet winter one year prior to survey year.

## METHODS

### DATA COLLECTION & PROCESSING

**Where:** 1-hectare plots (n = 22, not all plots surveyed in all years) in coastal San Diego County, California classified as **fragments (area < 120-ha)** or **reserves (area > 500-ha)**.
**When:** Once every three weeks Mar- Aug in 2011, 2012, 2015, 2016, 2022, and 2023 at 08:00-15:00 on each survey day.
**How:** Triplets (blue, yellow, and white) of bee bowls. Due to the bias in shifts in abundance detection as a result of passive traps[8], we limit our analyses to species richness.

All bees were curated to be vouchered at UC Riverside Entomology Collection (UCRC).

### ANALYSIS[9]

**Rarefaction:** Rarefied to the smallest sample size in all survey years (n = 70) and ran 1200 iterations. Mean rarefied species richness reported.

**Linear-mixed effect model[10]:**
- ***Response:*** Rarefied richness
- ***Main effect:*** Precipitation one winter (3a) and two winters (3b) preceding survey season.
- ***Random effects:*** Year and survey site

*Reviewed summary statistics with 'emmeans'[11].*

**Indicator Species Analysis[12]**
Precipitation from both one and two years prior survey season classified in terciles as high, medium, or low based on 25-year average. We used an association index to account for unbalanced survey efforts.

**Figs 5a-b.** Example of a survey fragment site in a dry year (May 2022) and a wet year (May 2023). San Miguel Mountain and a freeway intersection visible on the center right of each photo.

## CONCLUSIONS

**PRECIPITATION TIMING:** Bee assemblages respond more to precipitation from two years before the flight season, especially in **reserves**. There is a subset of indicator species abundant enough to be detected.

**HABITAT FRAGMENTATION + PRECIPITATION:** Increased precipitation enhances richness in **reserves,** but not in **fragments** (Fig. 3b, Table 1). This pattern suggests that bee assemblages have a lagged response to increased precipitation, but **fragments** lack the precipitation-sensitive species or these species' population sized are too small to detect.

**ACKNOWLEDGEMENTS: FUNDING:** UCSD Biological Sciences, NIH T-32 PiBS Fellowship, Jeanne M. Messier Grant, Sea and Sage Audubon, UCNRS Mathias Grant.
**ASSISTANCE:** Taxonomic expertise from J. Gardner, J. Gibbs, T. Griswold, M. Orr, Z. Portman, M. Rightmyer, K. Wright, and D. Yanega. Field and laboratory assistance from many Holway Lab undergraduate students since 2011. From 2022 – present: Ciara Casas, Zhenhao Feng, Yerin Go, Bianca Jussen, Sky Kezmoh, Lily Landre, Tristie Le, Kris Price, Bridget Spencer, Tim Swain, Rebecca Stiling, Bautista Tobias, and UCSD Pollinator Club. **PERMITS:** The UC Natural Reserve System, Open Space Parks in San Diego County, and the Otay-Sweetwater Unit of the San Diego National Wildlife Refuge.
**REFERENCES: 1.** Wagner, D. L. *Annu Rev of Entomo* 65 (2020) **2.** Jaureguiberry, P. *et al. Sci Adv* (2022) **3.** Myers, N. *et al. Nature* (2000) **4.** Jong, B-T. *et al. Environ Res Lett* (2016) **5.** Hung, K.J. *et al. Ecol* (2019) **6.** Hung, K.J. *et al. PLOS One* (2017) **7.** Hung, K.J. *et al. Insects* (2021) **8.** Kuhlman *et al. Ecol Solut Evid* (2021). **9.** R Core Team (2024) **10.** Bates, D.M. Package 'lme4' (2010) **11.** Lenth, R. *et al.* 'emmeans' (2023). **12.** De Cáceres, M. *et al. Methods Ecol Evol* (2012)