Effects of co-occurring urban atmospheric compounds on desert herbaceous plants

Elizabeth M Cook[1], Pamela Padgett[2], Sharon J Hall[1]
[1]School of Life Sciences, Arizona State University, Tempe, AZ [2]Pacific Southwest Research Station, United States Forest Service, Riverside, CA

Central Arizona-Phoenix Long-Term Ecological Research CAP LTER

Urban air quality impacts on ecosystems

Cities occupy a small area of Earth's land, but urban-generated compounds, such as elevated **carbon dioxide (CO_2), ozone (O_3)** and **nitrogen (N) deposition**, impact air quality at local to global scales.

Despite their ecological relevance as a resource or stressor to primary producers (**Table 1**) and co-occurrence of elevated CO_2, O_3 and N (**Table 2**), the net impact of co-occurring compounds on ecosystems at realistic concentrations is unknown.

Table 1: Common urban-generated atmospheric compounds that act *individually* as either a *resource* or *stressor* to primary production

Common urban atmospheric compounds	***Ecological relevance to primary production***
Carbon Dioxide: CO_2	Increase water-use and nitrogen-use efficiency, ***stimulate production***
Ozone: O_3	Foliar cell damage, ***inhibit photosynthesis*** and stomatal conductance, early senescence
Reactive Nitrogen: N e.g. Nitric Acid (HNO_3), Ammonium Nitrate (NH_4-NO_3)	Alleviate nutrient limitation, ***stimulate primary production***, alter species composition

Research Question

Using dominant Sonoran Desert herbaceous species and the Central Arizona-Phoenix (CAP) LTER site as a model system, we ask, what is the sensitivity and net response of ecosystems to co-occurring CO_2, O_3 and N?

Hypothesis: Desert winter herbaceous species will be ***sensitive to elevated co-occurring compounds with overall non-additive responses*** because annual plants respond quickly to small environmental changes during their short growing season.

Elevated atmospheric levels across Phoenix currently exceed standards

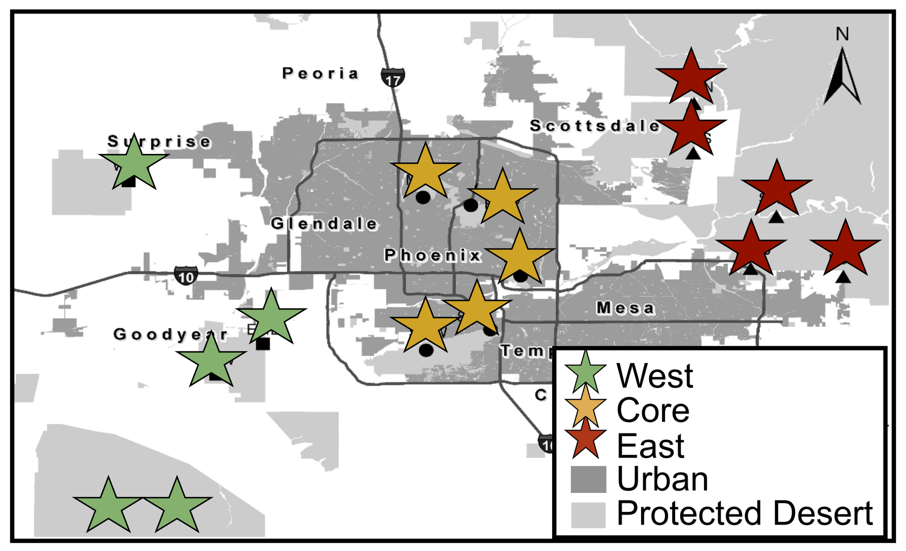

Figure 1: Urban and protected desert within the CAP LTER study site. Stars indicate CAP long-term N deposition monitoring sites.

Table 2: Known (O_3 & N) and predicted (CO_2) levels across the Phoenix region exceed current regulatory air quality standards for humans and ecosystems.

	West	Core	East	***Standards***
CO_2 (ppm)[1]	390-400	490-620	390-400	***No regulation***
O_3 (ppb)[2]	66	85	80	***75***
N deposition (NO_3 + NH_4 kgN ha^{-1} y^{-1})[3]	2.9 (+/-0.7)	4.4 (+/-2.2)	3.3 (+/-0.7)	***3 - 8***

Desert annuals are sensitive to O_3 and HNO_3 at Phoenix concentrations

In 6-week fumigation, we examined native and non-native winter annual plant production and physiological responses (e.g. photosynthetic parameters) to elevated O_3 and HNO_3 in high and low water treatments (**Fig 2, Table 3**).

Figure 2: Continuously Stirred Tank Reactor (CSTR) Chambers, University of California, Riverside

Table 3: Pilot study treatments in each CSTR chamber

	O_3 (ppb)	HNO_3 (ug/m³)	CO_2 (ppm)
1: Control	~ 10	None	Ambient
2: Low O_3	35	None	Ambient
3: High O_3	90	None	Ambient
4: HNO_3	None	10	Ambient

Native & non-native species' expected differences

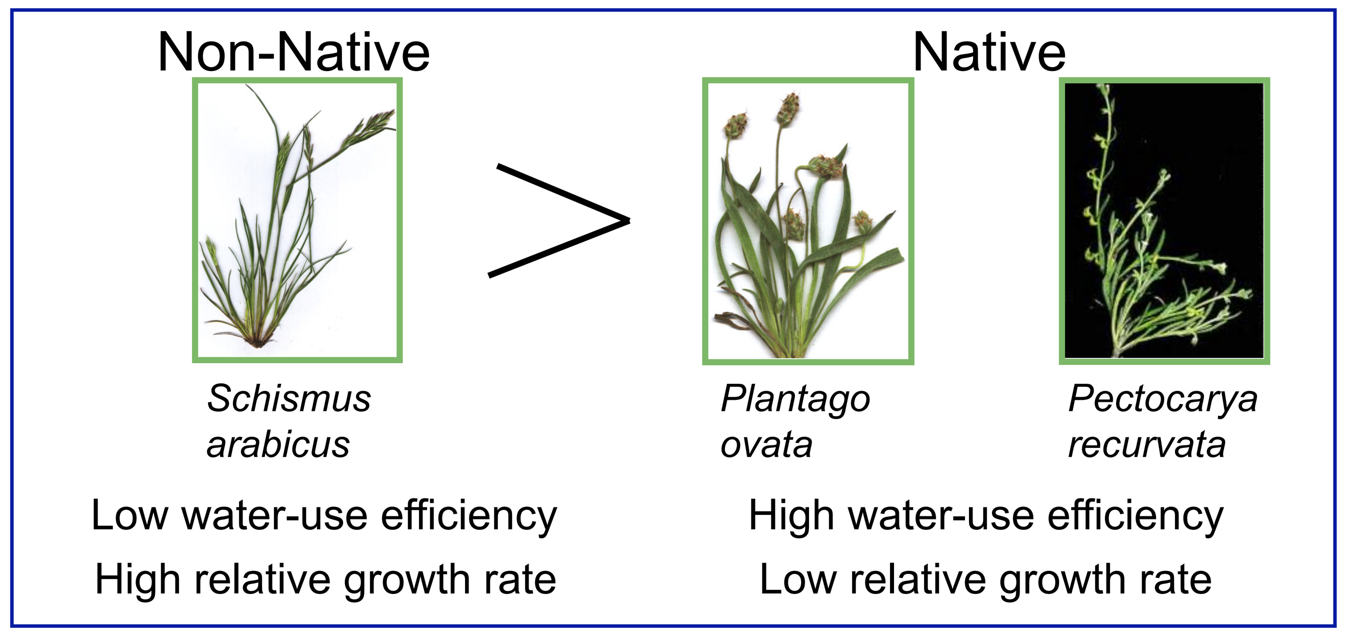

Figure 3: We expected *S. arabicus* (non-native) to be more sensitive to elevated O_3 & HNO_3 due to higher growth rate & lower water-use efficiency than native species.

Schismus arabicus less sensitive than expected

As expected, all species grew significantly more with lower mortality rates in reduced water stress (**Fig 4**). Elevated O_3 did not negatively affect *S. arabicus* (**Fig 4a**), while the native species grew less in higher O_3 (**Fig 4b & 5**).

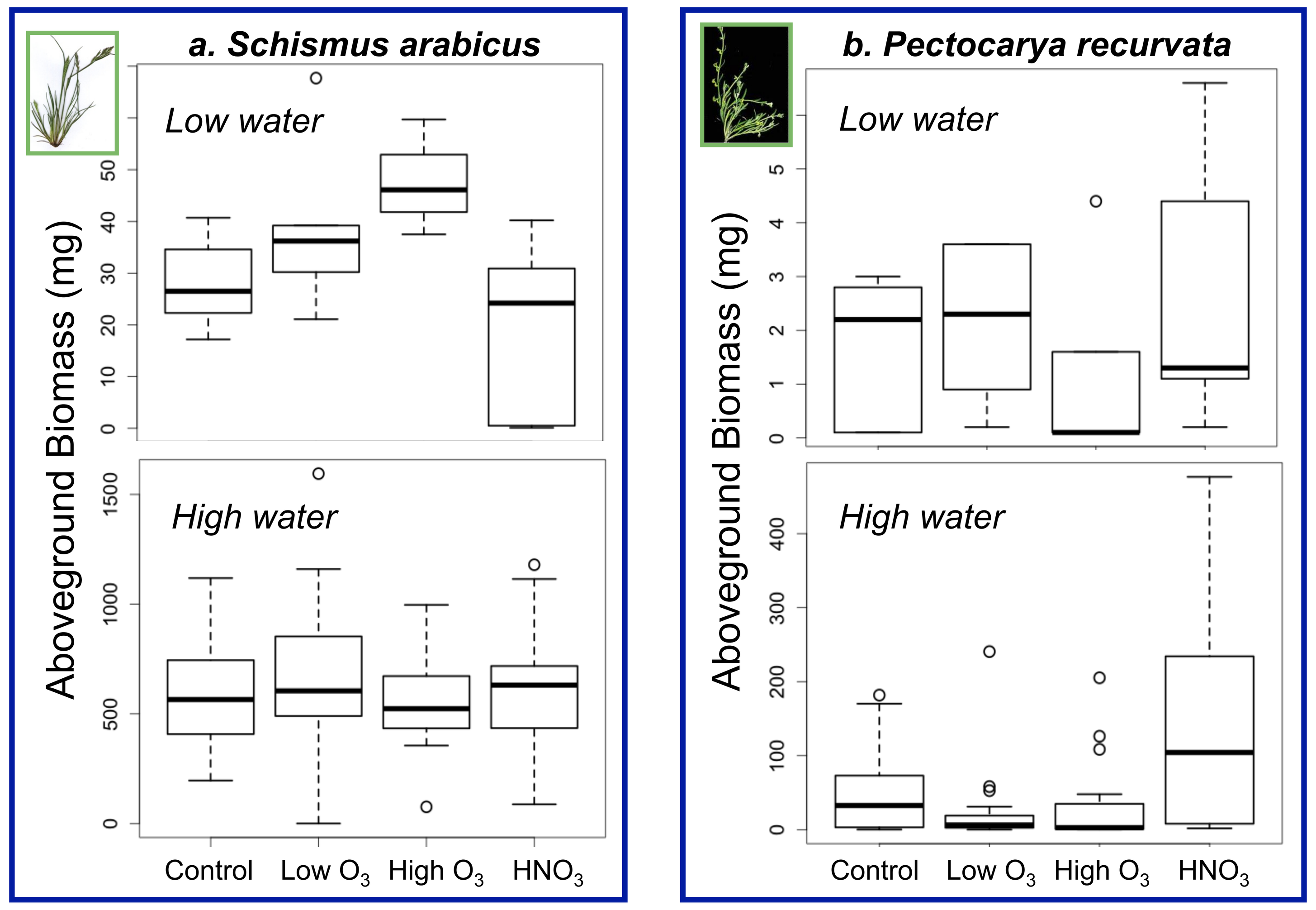

Figure 4 (a) *S. arabicus* and **(b)** *P. recurvata* median (dark line) dry weight aboveground biomass (mg) in low (top panels) and high (bottom panels) water treatments.

Unexpected response to HNO_3

Nitric acid was expected to negatively affect physiological functioning and reduce primary production. However, with unlimited water, native species, particularly *P. ovata*, grew significantly in response to elevated HNO_3 (**Fig 5**), whereas *S. arabicus* did not (**Fig 4a**).

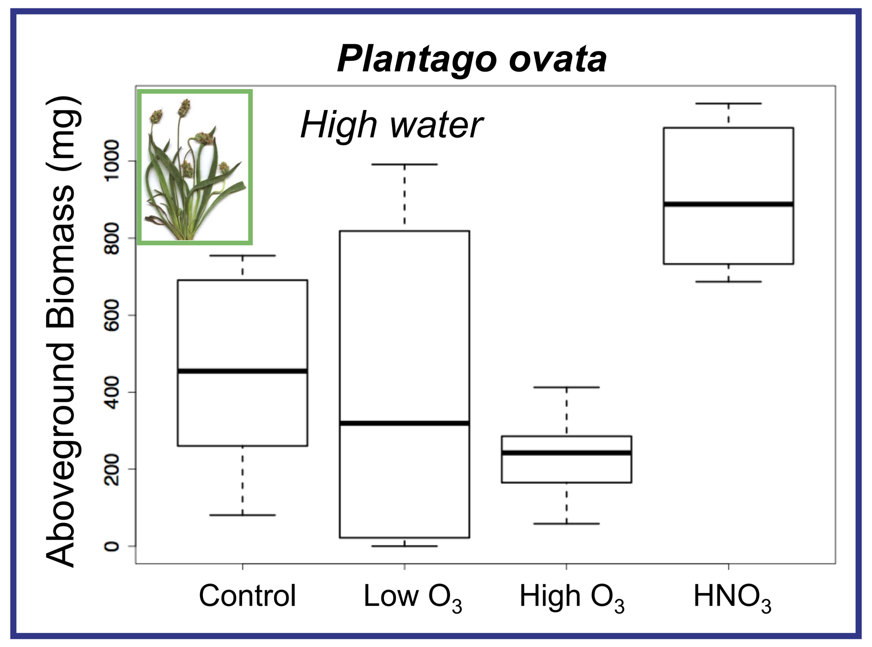

Figure 5: *P. ovata* dry weight aboveground biomass (mg) was significantly greater in elevated HNO_3 than other treatments. To support this finding, *P. ovata* from HNO_3 treatment had significantly higher max quantum efficiency (Fv/Fm = measure of Photosystem II ability to tolerate stress) than in other treatments (data not shown).

Next steps toward multi-factor critical loads

We plan to conduct a **multi-factor dose response experiment** using treatments with a range of CO_2, O_3 and N conditions (**Table 4**) to determine sensitivity to co-occurring factors.

Table 4: Multi-factor dose response treatments. O_3 & CO_2 fumigation with multiple N treatments within each chamber.

	O_3 (ppb)	N (kg/ha/yr)	CO_2 (ppm)
1: Control	Ambient (~15)	0, 2, 4, 8	Ambient (~380)
2:	15	0, 2, 4, 8	550
3:	15	0, 2, 4, 8	700
4:	60	0, 2, 4, 8	Ambient
5:	60	0, 2, 4, 8	550
6:	60	0, 2, 4, 8	700
7:	100	0, 2, 4, 8	Ambient
8:	100	0, 2, 4, 8	550
9:	100	0, 2, 4, 8	700

Critical Load: The level of pollution at which negative ecological effects occur, but is often determined for single pollutant rather than for realistic ecosystem exposure to co-occurring compounds.

With the empirical evidence from this research, **multi-factor critical loads** can account for ecosystem sensitivity to co-occurring stresses.

Conclusions

Within the pilot study, non-native species were less sensitive to elevated O_3 and HNO_3 than expected and may be more resistant to atmospheric pollutants than native species.

Through this research, the overarching goals are to quantify:

Ecological sensitivity and thresholds in response to multiple chronic impacts at realistic concentrations, and

Provide empirical evidence for a multi-factor critical load for management decisions to preserve native ecosystems & human health within the "airshed" affected by co-occurring pollutants.

References: 1 (CO_2): Wentz et al 2002; no set CO_2 standard; **2 (O_3)**: Maricopa County Air Quality Dept data; EPA O_3 standard; **3 (N)**: CAP-LTER long term N deposition database; Fenn et al 2010 desert N critical load.
Acknowledgements: We especially thank David Jones (USFS, Riverside CA), Elizabeth Hessom and Lou Santiago (UC Riverside), and all members of the Hall lab for their discussions, help and use of facilities and equipment. This work is based upon work supported by the National Science Foundation under grant no. DEB-0423704 and BCS-1026865 CAP LTER.