Proposal Addendum

CAP3: Urban Sustainability in the Dynamic Environment of Central Arizona

The Central Arizona–Phoenix LTER program has proposed continuing and new research to address the challenging question, *How do the services provided by evolving urban ecosystems affect human outcomes and behavior, and how does human action (response) alter patterns of ecosystem structure and function and, ultimately, urban sustainability, in a dynamic environment?* The portfolio of research is broad and each component sub-project (e.g., the CAP3 long term observations, models, and experiments under two areas: foundational/crosscutting research and integrative project areas) has its own set of questions, hypotheses, and expectations. In addition, research is conducted at multiple scales and, of necessity and by design, is place-based; therefore, the domains to which research findings might reasonably be expected to apply may vary.

As a result of this complexity, the LTER renewal panel expressed some concern about the logical development of some of the research, as well as the connections among different sub-components of the research. They asked the CAP3 PIs to explain, in an addendum, the following points for each of the “proposed experiments”:

1. What is the answerable question that will be addressed by this experiment?
2. What are the treatments and controls, and what is the rationale for this set of treatments?
3. What is the domain (or scale) of inference to which the results of each experiment can be applied?

In response, we have prepared the attached table that lists each of the experiments or observational studies mentioned in the panel summary as problematic, as well as selected others, with a summary of the three requested points and cross-referencing to the proposal section and the overarching questions addressed by the research. Table 1 satisfies not only the specific enumerated points requested, but also, in part, the following panel comment: “The panel would have liked to see all of these goals, questions, and hypotheses together in a common table, chart or figure to show their relationships, and in particular to illustrate how the sub-questions and hypotheses will inform answers to the larger questions.” Although we, too, would like to see all of this together we suspect it would be impossibly large and unwieldy and we believe that the selection of studies Table 1 is sufficient. Although our proposal only includes three actual experiments in the strict (manipulative) sense (NDV residential landscape manipulation, long-term fertilization, and bird foraging/competition experiment), like the panel we use a broader definition of experiments in our response.

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Proposal section (page)	Team	Answerable question (keyed to overall questions 1, 2, 3) and rationale	Experimental/study design and treatments	Domain of applicability
A1 (18)	FCR: LULCC	Q: How does land architecture affect the spatial distribution of ecosystem services? (1) Rationale: Land architecture comprises the kinds, amounts, distributions, and patterns of land covers or uses (Turner 2009). Studies of the dynamic change in land architecture serve as the foundation for many other investigations; without knowing the historical, current, and developing patterns of land use and cover it would be impossible to uncover land-use legacies, scale up measurements made at the patch scale, or project future ecosystem processes. Basic information on land cover is foundational for any study of SES change that involves land-use change, such as urbanization.	Although this research activity is not a single experiment *per se,* it is fundamental to many continuing and proposed research projects. The design incorporates two scales of resolution (1 m, 30 m) for years corresponding to Survey 200 and PASS (2010, 2015, 2020…). Land-cover classifications will yield GIS-based spatial distributions of 1) built structure, including impervious surfaces, 2) vegetation of differing types, 3) unvegetated spaces, and 4) water, from which numerous measures related to ecosystem services (such as climate regulation, stormwater regulation) can be extracted (see proposal for detailed list of metrics to be extracted from classified imagery). In addition to these measures extracted directly from the products of this activity, the resulting GIS layers can be overlain on Survey 200, PASS, and Census data to examine spatial correlations between land parameters and biophysical, social, and economic data (see, for example, Survey 200 below). The two scales are embedded in a third scale (250-m resolution) being analyzed for the central Arizona megapolitan region with other sources of support.	Land classifications will apply only to the specific scenes analyzed. Parallel classifications in Tucson, AZ are being done as part of a comparative study of stormwater (Lohse, Earl, et al., NSF-Ecosystems), in BES, PIE, and FCE as part of a comparative study of residential landscapes (Larson, Polsky, Grove, et al., LNO), and in five LTER sites (KNZ, SEV, SGS, JRN, CAP) as part of a cross-site study of land fragmentation. Thus, although images themselves are specific to a place, their use to uncover relationships of land configuration, pattern, and type (e.g., land architecture) to biophysical and social variables is generalizable to a broad array of systems.

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A2 (18-19)	FCR: NDV	Q: What is a sustainable residential landscape in the arid Southwest, as judged by tradeoffs and costs? (1, 2, 3) Rationale: Sustainable landscapes as those that are designed, installed, and managed in ways that meet the needs of the present without compromising the needs of future generations (Martin, 2008). Ecosystem services provide a measurable framework for assessing landscape site sustainability. Data collected at the NDV experiment will be specifically aimed at defining the scope and dynamic of ecosystem services, specifically: microclimate regulation (i.e., heat mitigation), water conservation, carbon sequestration, ecosystem and/or species preservation, aesthetics and sense of place. Thus, the question is answerable because we can determine the efficacy of each landscape treatment in delivering these specific ecosystem services.	The NDV experiment is four treatments (plus control) that were specifically chosen in CAP2, based on preliminary studies of residential landscapes types within the Phoenix metropolitan region from 1990 to 2002. In an arid environment, plant structural composition of residential landscapes is directly related to intensity of biophysical inputs (especially of water). The costs or benefits of these biophysical inputs determine the value of ecosystem services provided by residential landscapes. Our treatments reflect landscape design typologies across the Phoenix metro area, varying in water delivery amount and method, ratio of turf grass surface cover to inorganic surface cover, and diversity of tree and shrub species. The experiment will allow testing of hypotheses describing benefits and costs associated with increased intensification of landscaping management. Treatments are: *Mesic*– 100% turfgrass cover, sprinkler irrigation, exotic high water use evergreen and deciduous landscape plant taxa; greatest mitigation potential for urban heating. *Oasis*– 12% turf cover, 88% decomposing granite mulch cover, mixture of sprinkler and drip irrigation, mixture of high and low water-use, exotic plant taxa; most popular landscape design style in Phoenix. *Xeric*– 100% decomposing granite surface mulch cover, drip irrigation, low water-use, exotic plant taxa; most common water-conserving landscape design in Phoenix. *Desert*– 100% decomposing granite surface mulch, no irrigation, Sonoran Desert plant taxa; maximum potential for preservation of Sonoran Desert within urban matrix. *Control*– not manipulated, non-vegetated, no intentional biophysical inputs; uncommon.	The NDV experimental suburb is the first such experiment of its kind (Cook et al. 2004). As for any experiment, the applicability beyond the specific site in which it is applied must be established through comparative studies, examining assumptions, and attempting to scale results to a broader area using models. Because our treatments are the most common, and contrasting, residential landscape types in the Phoenix metropolitan area, we believe our biophysical measurements will apply broadly to the domain of residential landscapes in Phoenix and other cities in hot, arid climates. However, the domain to which our social science results apply is more restricted because of the small sample size and particular demographic of the NDV residents. We have already conducted comparative analyses, however, of the residential yard choices made by NDV residents and PASS neighborhood residents (Larson et al. 2009).

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A3 (20)	FCR: Survey 200	<u>Q</u>: How are key biophysical variables distributed across the CAP region, and what variables explain this distribution? How is this distribution changing over time? (1, 2) <u>Rationale</u>: This question was first framed during CAP1, when the Survey 200 was designed. It allows us to evaluate a "null" hypothesis that a suite of independent biophysical variables typically invoked in ecological studies best explain the key biophysical variables that we measure. In studies to date, we have rejected the null hypothesis, finding that socioeconomic and land-history factors must be included. With our third and fourth surveys conducted in 2010 and 2015, we will begin to evaluate temporal change.	A spatially extensive and explicit sampling design was selected to ensure that no bias was introduced by a priori assignment of land-use types. The dual-density, tessilation-stratified design randomly assigned 204 points across a 5 km x 5 km grid covering the 6400 km^2 study area, with each grid square containing a point within the core urban area but only every third square containing a point in the surrounding desert and agricultural regions. Each point is at the center of a 30m x30m plot, in which biophysical variables are measured and samples collected once every five years. In CAP3, we added the largest contiguous residential parcel for each residential plot (~one third of the points). Analysis generates maps of biophysical variables and uses hierarchical Bayesian modeling to test their relationships to candidate predictor variables (e.g., Kaye et al. 2008). They also can serve as input to other spatially explicit data (arthropod and bird monitoring, social survey [PASS] data, etc.) Here is a good example of how the land classification (A1) is used to generate a richer dataset. Techniques are now being developed to understand the temporal dimension of change in biophysical characteristics.	The domain for this observational dataset is the 6400 km^2 central Arizona region, including the broad categories of urban, agricultural, and wild lands, for the variables included in the survey. However, the survey was designed with the expectation that data would be usable in the U-FORE modeling environment; indeed, the data have been input into U-FORE to generate carbon sequestration estimates for the region's trees (McHale et al. in preparation). Again we stress that, although these data cannot be applied to other cities, the relationships we describe between the variables and various predictive factors should be generalizable to a broader array of urban environments.
B2, Q2 (26)	IPA: Water	<u>Q</u>: Can riparianization be accomplished in a sustainable manner—where water use and alteration of the natural hydrologic system are minimized while also retaining related ecosystem services—during urbanization? (1, 3) <u>Rationale</u>: We defined sustainability on p 13 of the proposal, and in A2, above, we explained our rationale of using ecosystem services tradeoffs as a framework for evaluating sustainability.	Our experimental design is a Before-After-Control-Intervention (BACI) design. The <u>*control*</u> or <u>*reference*</u> will be the pre-development condition, <u>*treatments*</u> will be the various configurations of drainage, land-use change, and impervious surfaces that result from designs that are co-produced with the developer(s). tRIBS modelling will be critical to understanding how pattern changes accompanying development affect ecohydrologic processes. With the focus here on ecohydrologic patterns, we ask whether developments can be sustainable in terms of the bundles of water-related ecosystem services they maintain, compared to the pre-development state. Co-production of the plan will largely be done in the Decision Theater.	The domain of this experiment will be the neighborhood or community that is being built out, but the domain of application of results will be relevant throughout the central Arizona megapolitan area and, to some extent, to any aridland urban ecosystem. Relevant water-related ecosystem services are the regulating services of stormwater, water quality, and climate modulation, and cultural services associated with vegetation and water features.

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B3, Q1 (28)	IPA: BGC	Q: How can nutrient management at the household scale reduce human impacts on biogeochemical cycles? (2, 3) Rationale: Biogeochemical cycles described at the whole-ecosystem scale (metropolitan region) show dramatic impacts of human activity—but this is the collective impact of millions of individual people making individual choices. Understanding the choices that people make (which is, in fact, management) can reveal where incentives or disincentives might be effective strategies to reduce the metropolitan "footprint" for nutrients such as N, P, and C.	This research activity is planned to interface with the PASS, to add a series of questions to the 2011 survey of neighborhoods that will provide input to the Household Flux Calculator (HFC). The HFC computes inputs and outputs of C, N, and P on a household scale, and has shown that small changes in behavior can reduce fluxes of these elements without a major change in lifestyle (Baker et al. 2007). Within the sampling framework of PASS, we have 40 neighborhoods that vary in socioeconomic status, location, and other characteristics. We will use this variation to extend the HFC model to a greater variety of consumption levels in an arid, compared to a mesic, urban ecosystem. Although this is not a manipulative experiment, the "treatments" (in a statistical sense) may be viewed as the different levels of median family income, percentage college degrees, etc. that typify the PASS neighborhoods.	The specific spatial scale of this research is the household, a social scale that is highly relevant to human consumption choices. The domain to which we can expect our results to apply would encompass the Phoenix metro area, but should be relevant to other urban areas in arid lands. Using an approach that is based upon the Twin Cities HFC approach will allow us to evaluate the extent to which biophysical or demographic setting changes the human impact on biogeochemical cycles. Finally, the fact that we have already developed city-scale nutrient budgets allows us to evaluate the household fluxes in context.
B3, Q2 (28-29)	IPA: BGC (C,N deposition)	Q: What factors limit desert plant production, and does nutrient limitation change under the influence of the urban atmosphere? (1) Rationale: After water, deserts of the US Southwest are usually said to be nitrogen-limited. Given higher N deposition in the urban environment (a by-product of fossil fuel combustion), we anticipated that N would limit desert production outside the city, but not inside.	This long-term fertilization experiment was set up with leveraged funds (Grimm et al. NSF-Ecosystems, 2005-2008) and has been incorporated into the CAP research infrastructure. Five sites each in upwind and downwind desert and urban remnant desert parks (15 total) were established. *Treatments* include N, P, and N+P fertilizer added twice per year to 20m x 20m plots at each site; *controls* are similar plots receiving no fertilizer. There is one set of treatments+control per site. Production of creosotebush (as stem length) and annual plants (total aboveground biomass) are measured annually; predictions are standard for this type of experiment and not repeated here.	As with any experiment, the domain includes the specific sites at which the experiments are conducted, but we expect to draw reasonable conclusions for unmanaged, lowland Sonoran Desert ecosystems within and outside of urbanized areas in the Southwest. Differences between our findings and those of a team working on N deposition effects in the Los Angeles area will be revealing, as LA's rates of deposition are much higher than those of Phoenix.

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B3, Q2, 3 (29, 30)	IPA: BGC (legacies, EJ)	Q: What determines the spatial distribution of soil nutrients and metals, and are certain populations disproportionately exposed to disamenities associated with these materials? (2, 3) Rationale: Soil sampling in Survey 200 are analyzed both for nutrients and metals. This question is a subset of the larger question concerning fates of materials in the urban ecosystem (B3Q2), but is also tied to the question about distributional equity associated with pollution disamenities (B3Q3). While we have conducted studies of the environmental justice implications of air pollutant distributions, soil pollution differs in that transport vectors are less strong and effects extend only short distances from the pollution source.	Answers to the first part of this question are covered in the description of Survey 200, above (A3), but for metals we also have obtained distributional data for possible sources (transportation, industry, agriculture, irrigation). Our study design to answer the second part of this question, as is the case for spatial distributions of air pollutants and, to a lesser extent, water-borne compounds, is to overlay socioeconomic data on spatial patterns of pollutant distribution and examine correlations between variables such as income, percentage ethnic minority, and educational level.	The relevant domain for understanding spatial distributions is the 6400-km^2 area of the Survey 200; for the environmental justice work it is the residential areas of Phoenix metro. We are limited in spatial resolution by the grid size of the Survey 200 (5 km x 5 km), but have used hierarchical Bayesian approaches to model distributions across the entire region.

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B4, Q1 (32)	IPA: BIO (competition experiments)	Q: How prevalent is interspecific competition in urban avian communities, and does the degree of interspecific competition differ among urban landscape types (e.g. mesic vs xeric suburban yards)? (1, 2) Rationale: CAP has contributed to development of theory about factors limiting species diversity in urban environments (e.g., Faeth et al. 2005, Shochat et al. 2006, Shochat et al. 2010). This question directly follows findings from long-term monitoring and seed-tray experiments that suggest urban environments have abundant resources and could potentially support many more species than are typically found. Our work has so far uncovered no evidence that predation is an important factor controlling diversity; on the contrary, giving-up densities on urban seed trays are much lower (i.e., birds forage longer) than in outlying deserts (Shochat et al. 2004). We therefore proposed these experiments to determine what species might benefit from protection from competition, and whether the type of residential landscape influences these outcomes. Bird diversity is a highly relevant metric associated with people's perceptions of the quality of their neighborhoods (Kinzig et al 2005.).	The experiments employ two different types of artificial feeding stations: 1) trays with seed and sand mixtures on the ground (see Shochat et al. 2004 for further details) and 2) hanging seed feeders, such as are typical in suburban yards. In both sets of experiments, some feeding stations are designed to exclude dominant foragers, particularly species known to be suburban adaptors (sensu Marzluff and Rodewald 2008). For the first set of experiments, the treatments are seed trays covered by cages with small openings, excluding larger bodied species such as doves that are known to be highly efficient foragers in Phoenix. Controls are trays with cages with larger openings allowing all common species to pass. The trays are videotaped to obtain feeding rates of all birds visiting the trays. The proportion of seed remaining after 24h is also recorded. Treatment trays (large-bodied birds excluded) are predicted to show: greater visitation by smaller bodied bird species, fewer aggressive interspecific encounters, and higher quitting harvest rates. For the second set of experiments, house sparrows are the target species to exclude. These globally distributed birds are consistently the most abundant species in Phoenix (Shochat et al. 2010). The experiment tests whether competition occurs between house sparrows and other small-bodied native species, such as the lesser goldfinch. The exclusion treatment makes use of a foraging adaptation finches possess that the sparrows do not: the ability to glean food while hanging upside-down from a perch. On a typical bird feeder, the food-dispensing hole is above the perch. By both inverting the feeder and shortening the perch, food are rendered accessible to finches but inaccessible to house sparrows. Treatments and controls will be applied sequentially, systematically varying the order of presentation, with residential yards as the experimental unit. Sparrow exclusion treatment days are predicted to yield higher visitation rates of native species, particularly lesser goldfinch.	The scale of inference that we aim for is residential yards in the Phoenix metropolitan area. We anticipate n>10 for residential yards of each type (mesic, xeric). By using PASS neighborhoods, we ensure that results are applicable to a range of socioeconomic and biophysical conditions of neighborhoods in this desert city.

Proposal section (page)	Team	Answerable question (keyed to overall questions 1, 2, 3) and rationale	Experimental/study design and treatments	Domain of applicability
B4, Q2 (32-33)	IPA: BIO	Q: Can conservation and restoration of "natural" habitats within the urban environment restore features of "natural" animal communities? (2, 3) Rationale: Restoration in highly modified urban ecosystems is known to be fraught with the challenges of identifying appropriate "controls"—i.e., the reference system to which the restoration is targeted—and for this reason, many authors have called for attention to "designed ecosystems" (Palmer et al. 2004, Larson et al. in press), or "rehabilitation" or even "reconciliation" approaches (e.g., Rosenzweig 2003). For this reason we use quotation marks around the term "natural." The features in which we are interested are species composition and stress response.	This observational study will compare restored riparian areas (n=5) to unrestored areas (n=5) along the Salt River in metro Phoenix. The Salt has not had any baseflow since 1938, but "restoration" projects in the past decade have resulted in wetland plant colonization and a return of many species of birds and, presumably, herpetofauna. We suggest that reference systems, such as unmanaged riparian zones outside the city, are not appropriate controls, although abundant literature reports on species records for southwestern riparian zones will be used to identify species lists as the range of possible colonists. Our expectation is that species richness will increase and stress response indicators will decrease in the "designed ecosystems" associated with riparian restoration in the Salt River, compared to unrestored reaches. We believe this is a more appropriate comparison than with an unmanaged desert riparian zone, since we aim to understand the efficacy of human efforts to create a "better" riparian ecosystem in the city.	The domain to which these results can be applied is the Salt River, a highly modified urban desert river that may not have an exact analog elsewhere, at a scale that includes the current restoration projects in the region (usually, a river length of several km). The conceptual domain is diversity and stress response of herpetofauna and avifauna, although we anticipate that the sites established in this project will in the future be appropriate locations for biogeochemical or hydrologic studies of designed urban wetlands.

Proposal section (page)	**Team**	**Answerable question (keyed to overall questions 1, 2, 3) and rationale**	**Experimental/study design and treatments**	**Domain of applicability**
B4, Q3 (33)	IPA: BIO (food web)	<u>Q</u>: How do humans modify biodiversity by altering the structure of food webs? (1, 2) <u>Rationale</u>: Food webs add a trophic or consumer-resource perspective to the usual diversity-index measures of changes in biodiversity, which allows us to uncover the mechanisms accounting for biodiversity changes in an urban setting (e.g., Faeth et al. 2005). This approach has been used throughout CAP's history to summarize monitoring data but heretofore has not included a complete food web, with humans placed in their appropriate roles in a "connectance web."	Rather than being an experiment per se, the construction of an urban food web will synthesize existing information from long-term data on species composition in a compelling structure and together with PASS or other neighborhood-survey measures of non-trophic human impacts we will assess where humans have had the greatest impacts on biodiversity via modifying food webs (i.e., feeders, pesticide use, fertilizer use to increase productivity, etc.). This research question will be answered using a mensurative rather than manipulative experimental approach in which we compare food webs constructed in various urban landscape elements (and at different levels of hierarchical amalgamation) to a food webs in neighboring non-urbanized desert environments (again at different levels of hierarchical amalgamation). The urban hierarchy consists of patches (parking lots, urban yards, cropland) to the whole urban corridor. The non-urban hierarchy consists of patches (riparian, upland, bajada) to a regional scale, "whole desert" incorporating similar topography.	This will be a very generalized food web for an arid urban ecosystem. We expect the general model of a food web that incorporates deliberate and unintentional human actions to be useful for others working in human-dominated systems on questions of how human activities affect biodiversity. We expect the specific results to apply to residential landscapes and open space (i.e., mesic, xeric, desert remnant, and outlying desert) that have been the focus of our long-term data.