San Pedro Riparian National Conservation Area (SPRNCA)
Long Term Environmental Impacts of Artificial Light at Night

An Environmental Research Program of
STEM Laboratory, Inc.
(IRS 501(c)(3) tax-exempt non-profit
Tucson, AZ

Abstract

Rapid evolution of artificial light at night in the San Pedro Riparian National Conservation Area is one of many environmental threats to this unique ecological system. However, it has only recently been recognized as a threat and is among the least well studied factors in the future of this irreplaceable environment. STEM Laboratory, Inc., a non-profit research foundation, has developed novel and powerful techniques for the long term monitoring and evaluation of this threat, and has embarked on a program of monitoring, mapping, and characterizing the impact of light at night in this region. We describe the goals and methods of this program below.

1. Specific Aims

The goal of this program is to apply coordinated techniques of ground, airborne, and satellite measurement of light at night (LAN) to the task of characterizing the changing artificial light environment of the San Pedro Riparian National Conservation Area (SPRNCA).

These data will not only document changes in the SPRNCA, but they will be archived, with public access, for application in research programs geared to understanding the impact of LAN on specific groups of animals and migration behaviors for transient species.

Milestones for this program include;

- Completion of comprehensive baseline measurements of both sky brightness and surface brightness for the entire extent of the SPRNCA.
- Establishment of a SPRNCA light at night data archive.
- Implementation of regularly scheduled LAN data surveys of the SPRNCA.
- Creation of a SPRNCA LAN Newsletter.
- Initiation of collaborative LAN/wildlife ecology programs with community scientists.
- Initiation of a citizen-science program to generate complementary data sets to support the LAN analyses.

- Creation of a SPRNCA LAN speaker's bureau to educate key parties on the impacts of LAN on the future of migratory bird routes, animal behavior, and ecological systems of Southeastern Arizona.

2. Background

2.1 Significance

The U.S. Congress, in 1988, designated about 50 miles of the upper San Pedro River as the San Pedro Riparian National Conservation Area (SPRNCA). This river basin is bounded by the U.S.-Mexican border on the south, and lies halfway between the Rio Grande and Colorado rivers to the east and west [see Appendix A]. It is *the last free-flowing river in the southwest U.S.*, and has been described as *the rarest ecosystem in North America*, the desert riparian woodland.

The SPRNCA lies on one of four major North American avian migratory flyways, with about 12 million birds migrating along the river annually. Over 100 species of birds breed along the San Pedro, one of the most popular birding areas on the continent.

Likewise, the San Pedro ecosystem is host to a diversity of mammal, reptile, and insect species, and serves as a pathway for both animal and plant species between the U.S. and Mexico.

With the increase of population of the desert southwest, the SPRNCA is under pressure from several sources: incursion of roadways, intrusion of people, loss of habitat, introduction of non-native plant species, and depletion of scarce water supplies.

We now understand that artificial light at night can also take a toll on this ecosystem. The SPRNCA is surrounded by growing communities such as Sierra Vista, Huachuca City, Tombstone, and Benson to name a few. It is surrounded by state highways and bisected by Interstate 10.

As LAN attributable to these communities increases, we see growing "light domes' over population centers. These domes expand radially to slice through the SPRNCA, and reach upward to contribute to sky brightness.

Artificial LAN not only increases nighttime brightness, but the rapid shift toward more modern Light Emitting Diode (LED) sources is also changing the spectrum of nighttime light. LED's contribute to a distinctly more blue-white glow.

Most animals react to artificial LAN in a negative way. Such unnatural light can impact breeding behaviors, migratory navigation, food supplies, nesting habitat, and vulnerability to predation, among other effects.

Mitigation protocols can be devised. However, it is first critical to understand the patterns of LAN expansion, and the relevant effects of LAN. This cannot be accomplished until the nature and extent of the problem is characterized, which in turn requires objective measurement of light sources involved.

2.2 Relevant Experience

Principals of STEM Laboratory include PhD scientists who have an extensive history of light measurement and characterization, spanning astronomical measurements from rocket and observatory based instrumentation, to the development of photometers and airborne LAN measurement protocols.

STEM Laboratory has pioneered the use of four complementary types of LAN surveys, as described in Appendix B.

In recent years these protocols have been applied to a variety of environmental studies as indicated by publications listed Appendix C.

3. Methodology

This is a long term program that will be advanced on several fronts, all directly relevant to the impact of LAN on the SPRNCA. In this section we briefly describe a series of initial, and in some cases on-going, tasks that will be required to conduct the program.

Task 1. Baseline Measurements of LAN

The key to useful measurement is to create a baseline against which to compare future measurements. We made initial airborne baseline measurements of both sky and ground level brightness of the SPRNCA region in 2012. Since that time we have significantly upgraded LAN measurement capabilities. We will revisit and update the 2012 baseline data, and we will expand the baseline measurements to the portion of the SPRNCA north of Interstate 10, which has not been previously surveyed.

Baseline measurements will include all of the protocols listed in Appendix B, and will include sky brightness mapping as well as ground level light characterization.

Task 2. SPRNCA LAN Data Archive

All of the SPRNCA LAN data will be copied to a digital archive so that these measurements will be available to researchers and other interested parties for years to come. STEM Laboratory has library personnel experienced in creation and maintenance of digital archives to accomplish this task.

Task 3. SPRNCA LAN Data Surveys

For the multi-year duration of this program LAN surveys will be conducted on a regular basis. Airborne surveys of the SPRNCA region will be conducted quarterly, using simultaneous

up- and down-looking photometers. This will enable creation of large scale sky brightness maps of the region, as well as maps of the contributing ground brightness. Monitoring of lights on the ground will be augmented with high temporal frequency satellite images. Also made from the airplanes will be high dynamic range imaging (HDRI) of specific light sources of interest. Ground based Internet Sky Brightness Meter (iSBM) data will not only track high frequency changes in sky brightness, but they will serve as a weather log as well to enable extraction of weather effects from real LAN variations.

Task 4. SPRNCA LAN Newsletter

During this program we will inaugurate a quarterly newsletter to promote public awareness of the project and its results. This newsletter will supplement the Technical Reports and papers in the scientific literature already underway at STEM Laboratory (see Appendix C).

Task 5. Collaborative Science Programs

STEM Laboratory maintains a vigorous program of LAN data reduction and analysis. During the course of the SPRNCA project we will actively seek collaborations with interested biologists and ecologists who wish to apply our data to specific problems of wildlife and habitat conservation.

Task 6. Citizen Science Programs

This project lends itself well to citizen science and education and public outreach collaborations. These are well within the mandate of STEM Laboratory, which has a history of working with students and amateur scientists. In particular, we will recruit lay participants in hosting nodes within a sky brightness network of iSBM's for continual monitoring of sky brightness from multiple points along the San Pedro river. We will also recruit citizen scientists for help in monitoring insect, bat, bird, and mammal populations within our LAN measurement area.

Task 7. Speaker's Bureau

Scientists within STEM Laboratory, as well as other scientists in our collaborative research projects, will prepare presentations on various aspects of measurement of LAN as well as its impact on flora and fauna of the SPRNCA. This group of speakers will be available for presentations to clubs, associations, and educational institutions interested in the nature and future of SPRNCA.

4. Applications of LAN Measurements

The LAN measurements collected during this program are invaluable to several applications relevant to understanding and preserving the SPRNCA environment and its inhabitants.

The most basic LAN measurements take two forms: measurement of night time sky brightness as seen from below, and the ground level distribution of light intensity as seen from above. Together, these measurements also allow characterization of the ambient LAN environment near ground level.

LAN data are collected at a range of resolutions, both temporal and spatial.

Temporal resolution refers to the time cadence of measurements, and can track LAN variations on scales of minutes to years.

Spatial resolution refers to the size of detailed regions within a large area characterized by LAN measurements, and can be as small as an individual light or as large as a city block.

The LAN data are generally used for the following purposes:

- Baseline establishment – regardless of the application of LAN data, it is desirable to know light levels existing at the start of a project, in order to have a reference against which to compare future measurements. This is a critical function of the SPRNCA project.
- Trend analysis – ongoing LAN measurements are compared with the baseline over time to determine how the LAN environment is changing, in terms of location, magnitude, and speed.
- Habitat modification – inventories of flora distributions are compared with LAN maps to determine changes in habitat as a function of evolving lighting distributions. This can have an important impact on both wildlife distribution and migratory patterns.
- Wildlife behavior modification – inventories of fauna distributions are compared with LAN maps to determine changes in animal behavior as a function of artificial light at night.

Examples from STEM Laboratory work in southern Arizona include correlation of of bat flight patterns to roosting areas, where the flight paths are affected by the expanding light dome around Tucson, AZ. LAN studies have suggested that invasive plant species can follow expansion of artificial lights, to have complex impacts on animal habitat and food sources. Studies are underway to determine the impacts on birds, both indigenous and migrating species.

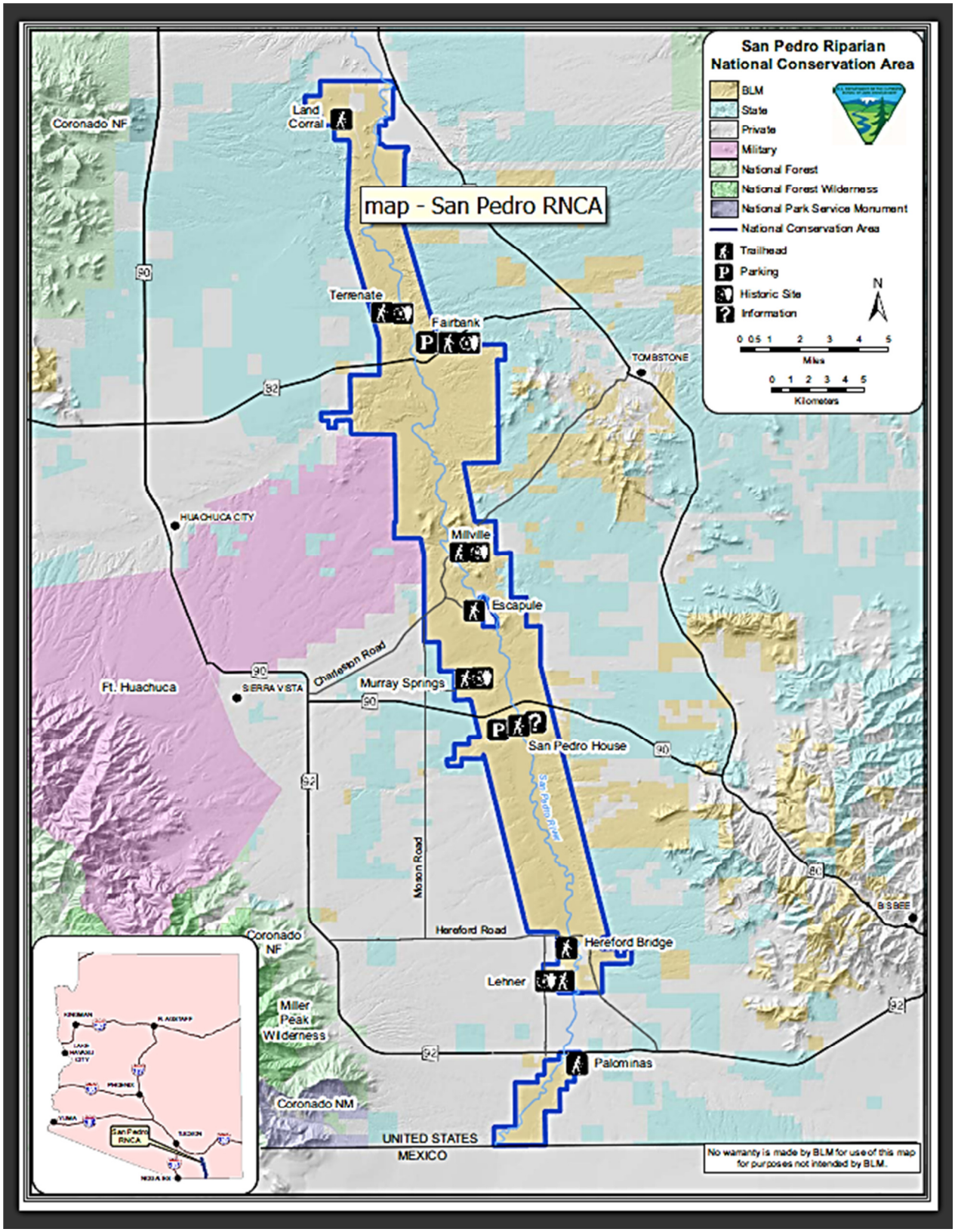
5. Funding Goals

Our funding goals for this program for the next five years of operation (2015 – 2019) are as follows:

2015	$ 500,000
2016	$ 550,000
2017	$ 605,000
2018	$ 666,000
2019	$ 750,000

Donations and sponsorships are tax deductible under our IRS 501(c)(3) status!

Appendix A. The San Pedro Riparian National Conservation Area (SPRNCA)



Appendix B. STEM Laboratory LAN Measurement Protocols

We conduct LAN measurements using several types of complementary instruments. Basic photometric instrumentation includes single channel luminance meters, single and multi-channel photometers, scientific grade CCD all-sky cameras, and high dynamic range imaging cameras. We have added the innovation of dynamic motion to some of our photometers by incorporating Global Positioning System (GPS) capability along with automatic data logging; these systems have been operated from a variety of moving vehicles, including both manned and unmanned aircraft. These tools are often augmented with satellite data. We operate these systems in four basic modes, briefly defined as follows.

Ground Static Surveys (GSS)

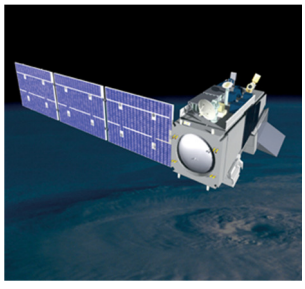
Ground Static Surveys involve using fixed photometric or imaging sensors at ground level to record ambient light intensity, usually at high temporal frequency, typically once every few minutes. These data are particularly useful for understanding how local light intensity is modulated by weather and human activity. However, it is limited in its ability to characterize light over large areas, or to discriminate specific lights impacting the site. It is useful to bear in mind that most astronomical observatory monitoring of LAN is in the form of the GSS.

Ground Mobile Surveys (GMS)

Ground Mobile Surveys use the same photometric detectors developed for the GSS, but they are mounted on vehicles and driven over prescribed courses, while continuously recording ambient light intensity. The photometers are equipped with Global Positioning System (GPS) receivers that allow us to record not only light intensity, but also position and time. These systems work most efficiently in more heavily populated areas where there are systematic networks of roadways over which to move the photometers. GMS are most useful for characterizing LAN on time frames of days or weeks, and over moderate sized communities.

Airborne Surveys (ABS)

We conduct Airborne Surveys using several different light detectors. These include up and down looking photometers of our own design and manufacture, as well as High Dynamic Range Imager (HDRI) 2-D CCD cameras. We use both manned and unmanned aircraft to carry these detectors over areas of interest. The ABS programs are best suited to larger areas than the GMS (typically city size or larger areas), for which high temporal frequency is not a requirement. They are uniquely well suited to high spatial and contrast resolution data collection.



Satellite Data Surveys (SDS)

There are small numbers of polar orbit satellites that are accumulating various types of LAN observations. We have developed software and methods for mining and exploiting these databases. The data tend to be inhomogeneous, and require great care in their use and application. They are often of low contrast resolution, and have lower spatial resolution than our HDRI ABS programs. Nonetheless, these data, when knowledgably and properly processed, provide a very useful complement to the other methods we have developed.

Appendix C. STEM Laboratory LAN Measurement Publications

Publications and Technical Reports

Craine, B.L., and Craine, E.R. "Artificial Light at Night Remote Assessment by Satellite" [STEM Laboratory: Tucson, AZ], pp 1-n, STEM TechRep-15-0701 IN PREPARATION (2015).

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Craine, B.L., and Craine, E.R. "Artificial Light at Night Distribution over the San Pedro Riparian Conservation Area" [STEM Laboratory: Tucson, AZ], pp 1-n, STEM TechRep-15-0601 IN PREPARATION (2015).

Craine, E.R., Craine, P.R., Craine, E.M., and Fouts, S. "A Strategy for Urban Astronomical Observatory Site Preservation: The Southern Arizona Example" Proc. SAS, 33, eds Warner, Bucheim, Foote, and Mais, 45 – 54 (2014).

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Recent Published Abstracts

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