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Natural Resource Stewardship and Science

The Distribution and Dynamics of Nighttime Lights in the Mediterranean Coast Network of Southern California

Cabrillo National Monument, Channel Islands National Park, Santa Monica Mountains National Recreation Area

Natural Resource Report NPS/MEDN/NRR—2016/1290

ON THE COVER
Nghttime lights in southern California in 2012.

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Cabrillo National Monument, Channel Islands National Park, Santa Monica Mountains National Recreation Area

Natural Resource Report NPS/MEDN/NRR—2016/1290

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This report received formal peer review by subject-matter experts who were not directly involved in the collection, analysis, or reporting of the data, and whose background and expertise put them on par technically and scientifically with the authors of the information.

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Abstract

The impacts of light pollution and its fluctuations at landscape scales are a concern of public land managers. More information on the distribution, intensity, and dynamics of light pollution in national parks will help improve management decisions. We examined the nature and extent of nighttime light on National Park Service protected areas using the Defense Meteorological Satellite Program-Operational Linescan System, which has provided annual nighttime light imagery at a 1-km pixel resolution since 1992. In particular, we examine the extent of nighttime light upward radiance or brightness in a time series from 1992 to 2012, and measure change during this period in Santa Monica Mountains National Recreation Area, Channel Islands National Park, and Cabrillo National Monument. Nighttime lights have been stable in Santa Monica Mountains National Recreation Area, have decreased in Cabrillo National Monument, and are extremely low in Channel Islands National Park. However, the upward radiance or brightness values in Santa Monica Mountains National Recreation Area (40) and Cabrillo National Monument (28) are very high compared to other national parks. Indeed, both are comparable with the two national parks in the United States with the highest upward radiance values (Cuyahoga Valley National Park 40, Hot Springs National Park 46). Monitoring nighttime light extent, intensity, time series, and change detection using the Defense Meteorological Satellite Program-Operational Linescan System should be a standard practice for all national parks in the United States due to no cost of data and the ease at which analyses can be undertaken. There are high temporal spaceborne imagery and field based methods that can also be used to inventory and monitor nighttime lights. Results from this baseline report identify areas that may deserve a high priority for nighttime light abatement, education programs, and outreach.

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Introduction

Human activities substantially affect most of the terrestrial biosphere, currently at rates and spatial extents far greater than in any other period in human history (Cinzano et al. 2001; Kerr and Ostrosky 2003; Grimm, Faeth et al. 2008; Grimm, Foster et al. 2008). Human disturbance in southern California has a significant influence on the landscape because this area is highly populated and human numbers continue to increase significantly (Underwood et al. 2009). Southern California contains 50% of California's human population (20 of nearly 40 million people), but only 10% of its land area (Barbour et al. 2007). Nighttime light pollution has been of increasing concern as it relates to protected areas (Rich and Longcore 2006; Davies et al. 2014). In the past century, the extent and intensity of artificial nighttime lighting has increased such that it has substantial effects on the biology and ecology of species in the wild (Longcore and Rich 2004; Hölker et al. 2010; Gaston et al. 2013).

The introduction of artificial light, either directly or indirectly, into the natural environment can affect a wide range of natural resources, including nocturnal wildlife, migrating birds, and insects (Longcore and Rich 2004; Pawson et al. 2014). For example, migrating passerine birds fly at night with reference to the stars and can be disoriented by lights from cities and towers (Gauthreaux and Belser 2006; Longcore et al. 2008). Amphibians, with vision far more sensitive than that of humans, are apt to be disoriented by light (Perry et al. 2008). Research into the ecological consequences of artificial nighttime lighting is revealing numerous connections between light pollution and species disruption (Hölker et al. 2010; Aubé et al. 2013; Gaston et al. 2013). Quantifying the amounts of light pollution allows park managers to make informed decisions and recommendations on proposed development or resource use to protect the night sky (Fancy et al. 2009; NPS 2014).

Many studies of nighttime light pollution distribution and impacts on protected areas use the Defense Meteorological Satellite Program-Operational Linescan System (DMSP-OLS), which has provided annual composite night-time light imagery at a global spatial scale since 1992 (Gillespie, Willis, et al. 2015). Previous research has used nighttime lights to measure changes in the distribution and time series of nighttime lights, light pollution, human populations, and energy use in a given area (Elvidge et al. 1997; Cinzano et al. 2001; Small et al. 2005; Agnew et al. 2008). Nighttime light imagery also provides a metric of the distribution of urbanization and is highly correlated ($r^2 < 0.90$) with economic activity, which may relate to the sustainability of protected areas (Doll et al. 2006; Small et al. 2005).

The National Park Service Inventory and Monitoring Program

The purpose of the National Park Service (NPS) Inventory & Monitoring (I&M) Program is to develop and provide scientifically credible information on the current status and long-term trends in the composition, structure, and function of park ecosystems, and to determine how well current management practices are sustaining those ecosystems. As part of the NPS's effort to improve park management through greater reliance on scientific knowledge, the primary role of the I&M Program is to collect, organize, and make available natural resource data and to contribute to the NPS institutional knowledge by transforming data into information through analysis, synthesis, and modeling of specific key vital signs. The I&M Program defines "Vital Signs" as a subset of physical, chemical, and

biological elements and processes of park ecosystems that is selected to represent the overall health or condition of park resources, known or hypothesized effects of stressors, or elements that have important human values.

The Mediterranean Coast Network (MEDN) is one of 32 monitoring networks across the NPS. The MEDN comprises three NPS units (Figure 1): Cabrillo National Monument (CABR), Channel Islands National Park (CHIS), and Santa Monica Mountains National Recreation Area (SAMO). The *Mediterranean Coast Network - Vital Signs Monitoring Plan* (Cameron et al. 2005) describes the rationale and basis for long-term ecological monitoring and provides the foundation for MEDN monitoring programs. During the I&M Program's Vital Signs selection process, landscape characteristics such as land use and land cover were determined to be critical components of ecosystem function. Changes in these characteristics resulting from urbanization are among the most important anthropogenic stressors known in our region. As a result, the MEDN recognized the need to monitor landscape dynamics at all three network parks. This MEDN Landscape Dynamics monitoring program uses remote sensing and field surveys to determine the status and long-term trends in land cover and land use, vegetation communities, phenological variability, and light pollution (Willis et al., in review).

This report constitutes the baseline trend report for the light pollution component of the Landscape Dynamics monitoring program. It describes the application of remote sensing methods to monitor changes in nighttime lighting throughout southern California, with more detailed analysis of the three MEDN park units (Figure 1). This report also expands upon our findings published in Natural Areas Journal (Gillespie et al. 2016).

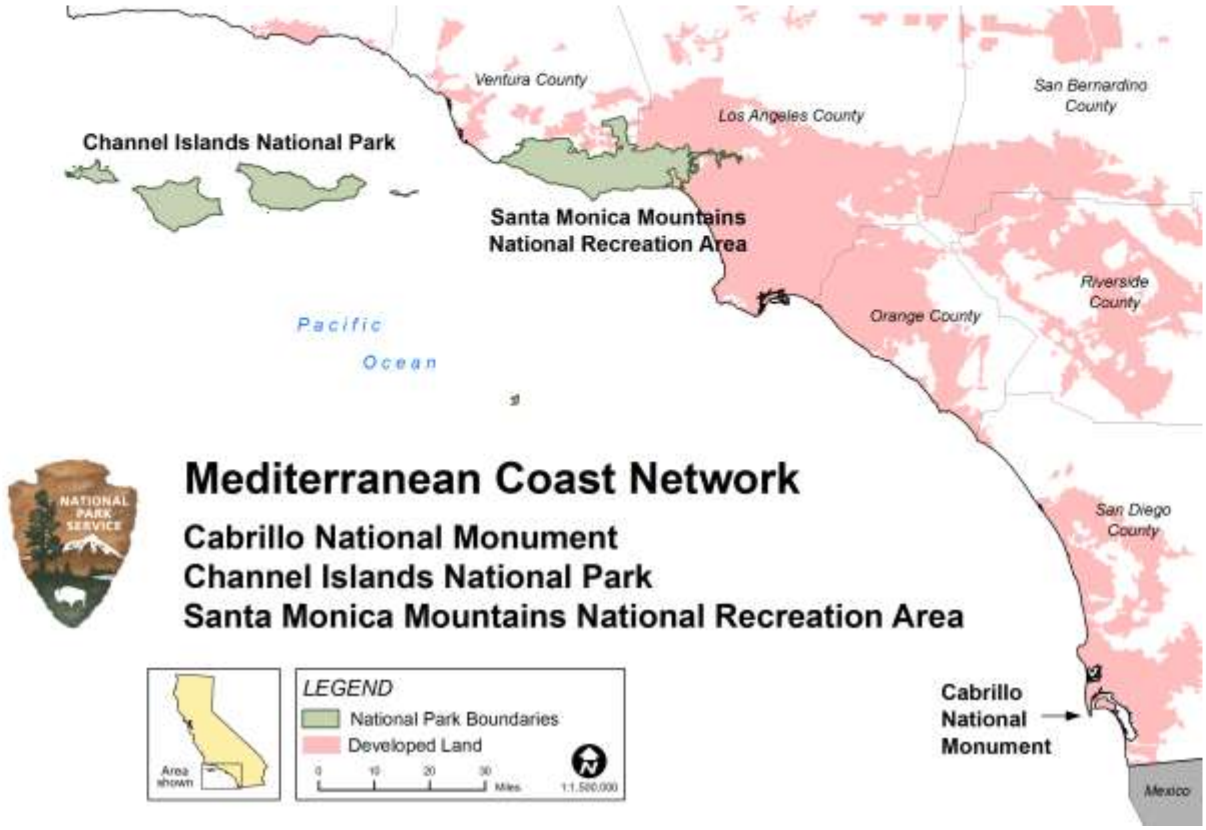

Figure 1. Locations of the three parks within the Mediterranean Coast Network of the NPS I&M Program.

In this baseline report we seek to:

1. Determine the status and trends in nighttime light intensity, distribution, and dynamics in the Mediterranean coast network of parks (Cabrillo National Monument, Santa Monica Mountains National Recreation Area, and Channel Islands National Park) as well as in the broader southern California region;
2. Establish nighttime light monitoring methods as a standard practice throughout the NPS system that transcends traditional program, activity, and funding boundaries; and
3. Integrate nighttime light monitoring information into NPS planning, management, and decision-making.

Study Area

Cabrillo National Monument (CABR)

Cabrillo National Monument (CABR) is located just west of San Diego at the tip of the Point Loma Peninsula (Figure 2). The Point Loma Peninsula is a four-mile-long mosaic of development and sensitive natural areas unique in southern California because of their climate and geology. Although CABR is the smallest park in the MEDN, comprising roughly 65 ha, the park is part of the 263 ha Point Loma Ecological Conservation Area (PLECA), a non-contiguous ecological reserve area created in 1994 by several federal agencies who hold ownership or stewardship over the lands on the Point Loma Peninsula. The PLECA sets aside "sensitive biological communities in amounts and configurations that would be viable in the long term on Point Loma" (Engle and Largier 2006).

Figure 2. Map of Cabrillo National Monument (CABR) within the Point Loma Ecological Reserve.

Santa Monica Mountains National Recreation Area (SAMO)

At 62,018 ha, Santa Monica Mountains National Recreation Area (SAMO) is the largest urban national park in the United States and is recognized by the International Union for Conservation of Nature (IUCN) as a Category V park because it experiences significantly high levels of human activity. The park is located within both Los Angeles and Ventura Counties (Figure 3) and includes privately developed areas such as Malibu and the Hollywood Hills. Within the recreation area boundary, the NPS owns and manages about 9,383 ha, or 15% of the total area. The remaining area includes privately owned land for both residential and commercial uses, as well as land owned by California State Parks and local land conservancies. About 90% of the land within the greater boundaries of SAMO is currently relatively undisturbed, natural habitat (NPS 2005).

Figure 3. Map of the Santa Monica Mountains National Recreation Area (SAMO).

Channel Islands National Park (CHIS)

Channel Islands National Park (CHIS) comprises five of the eight California Channel islands –Santa Barbara Island (SBI), Anacapa Island (ANI), Santa Cruz Island (SCI), Santa Rosa Island (SRI), and San Miguel Island (SMI) – off the coast of southern California, with a total land area of 51,012 ha (Figure 4).

Figure 4. Map of Channel Islands National Park (CHIS).

Methods

The distribution of nighttime lights in national parks was measured using 1992–2012 data from the Defense Meteorological Satellite Program-Operational Linescan System (DMSP-OLS) (Elvidge et al. 1997; Small et al. 2005). The DMSP-OLS provides panchromatic nighttime light imagery at a global spatial scale. DMSP-OLS was originally designed to view clouds by moonlight and to map the locations of permanent lights on the Earth's surface. The Defense Meteorological Satellites have a near-polar orbit at an altitude of 830 kilometers and contain visible and infrared sensors that collect nighttime light imagery at 30 arc-second or 0.9 kilometer pixel resolution across a 3000 kilometer swath (DMSP 2012). Each pixel provides a digital number value of nighttime light brightness as seen from space. Nighttime light imagery composites are collected annually based on stable night-lights. The stable night-light algorithm removes fires, lunar luminance, lighting features from the auroras, and cloud cover.

The purpose of this report is to map and quantify the nighttime lights, as well as identify individual regions that have experienced an increase or decrease in nighttime lights over time. We used visible pixel intensity derived from DMSP-OLS, which is available in relative digital numbers (DN) ranging from 0 to 63. The digital number is the illumination or upward radiance over the pixel area from direct or indirect energy sources, with diffuse lighting from bright areas impacting nearby areas. The digital number value saturates at 63 in high light environments and cannot then be used to determine increases or no change in nighttime light. We provide an example of what the land use/land cover types generally look like in southern California based on gradients of nighttime light intensity or radiance (Figure 5). The actual energy being emitted is highly correlated with the digital numbers. Elvidge et al. (1997) developed a digital number to radiance conversion scale using the function: Radiance = (DN) 3/2 x 10^{-10}. The results of this conversion and the raw digital number data from stable lights are highly correlated ($r = 0.96$, $P < 0.001$) (Gillespie, Frankenberg, et al. 2014). Thus we used cross-validated digital number in this baseline report for ease of analysis and to scale up to all national parks.

Data were obtained directly through the DMSP-OLS website (http://www.ngdc.noaa.gov/eog/). Once these data were obtained, brightness values for each pixel were calculated using ENVI software. Results were exported as an ASCII text file and then imported into ArcGIS for analysis. Change detection was measured using Change Detection in ENVI and the Raster Calculator in ArcGIS. The output data were displayed via intensity maps and change detection mapping of light values over each park, as well as through graphical representation of overall changes in brightness within the parks.

We analyzed nighttime light imageries acquired from 1992 to 2012. Nighttime images of California were obtained from the DMSP-OLS F10 (1992 to 1994), F12 (1994 to 1999), F14 (1997 to 2003), F15 (2000 to 2007), F16 (2004 to 2009), and F18 (2010 to 2012) satellites. The files were cloud-free composites made using all the available archived DMSP-OLS smooth resolution data for calendar years. In cases where two satellites were collecting data, two composites were produced. Each composite set was named with the satellite name and the year. The imagery used in this report was from stable lights from the most recently launched satellite.

We examined regional trends in nighttime lighting, current nighttime light distribution and intensity, time series trends, and change detection for the region, Santa Monica Mountains National Recreation Area, Channel Islands National Park, and Cabrillo National Monument. We compared lighting within distinct areas of each park using vegetation community overlays in GIS as a proxy for both land cover types in parks and general habitat characteristics. We also generated digital number values for all 59 national parks in the US and present the results in Appendix B for comparison to the southern California park units (Appendix A, Elvidge et al. 2014).

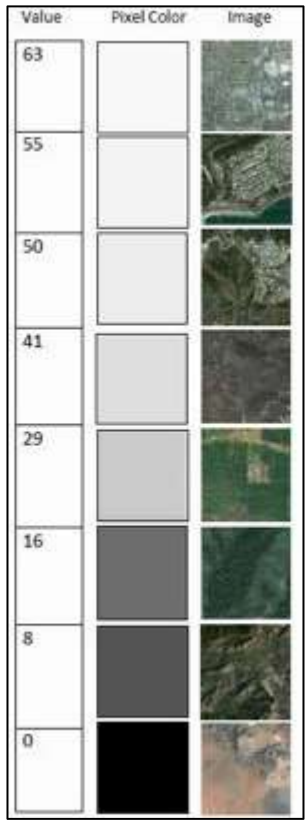

Figure 5. Digital number (DN) value from DMSP nighttime light data, gradients of DMSP nighttime light intensity, and images of corresponding land cover land use type in Southern California.

Results

Southern California

Nighttime lights in southern California are most intense in the Los Angeles Basin (Figure 6). Inland areas and the Pacific Ocean are the least impacted by light pollution. The cities of Los Angeles and San Diego are the most impacted by light pollution, and the coastal areas from Malibu south to the US/Mexico border are continuously impacted by light pollution.

Figure 6. Nighttime lights in southern California in 2012 as seen from space (source: David Gao, http://nationalparksnightlights.blogspot.com).

Southern California has seen a mix of increasing, decreasing, or stable nighttime lights during the monitoring period, depending on the area (Figure 7). In particular, natural areas and deserts have remained stable between 1992 and 2012. There have been increases (> 5 DN) in nighttime lights in new developments and suburban areas, which can be seen in cities like Santa Clarita, Lancaster, and Palmdale, agricultural areas in the Central Valley, and regions near the US/Mexico border. Nighttime lights have decreased (< 5 DN) over the San Gabriel Mountains and over the Pacific Ocean since 1992. Highly urban areas such as the city of Los Angeles appear to have remained stable, but this may be a result of saturation on the DN scale.

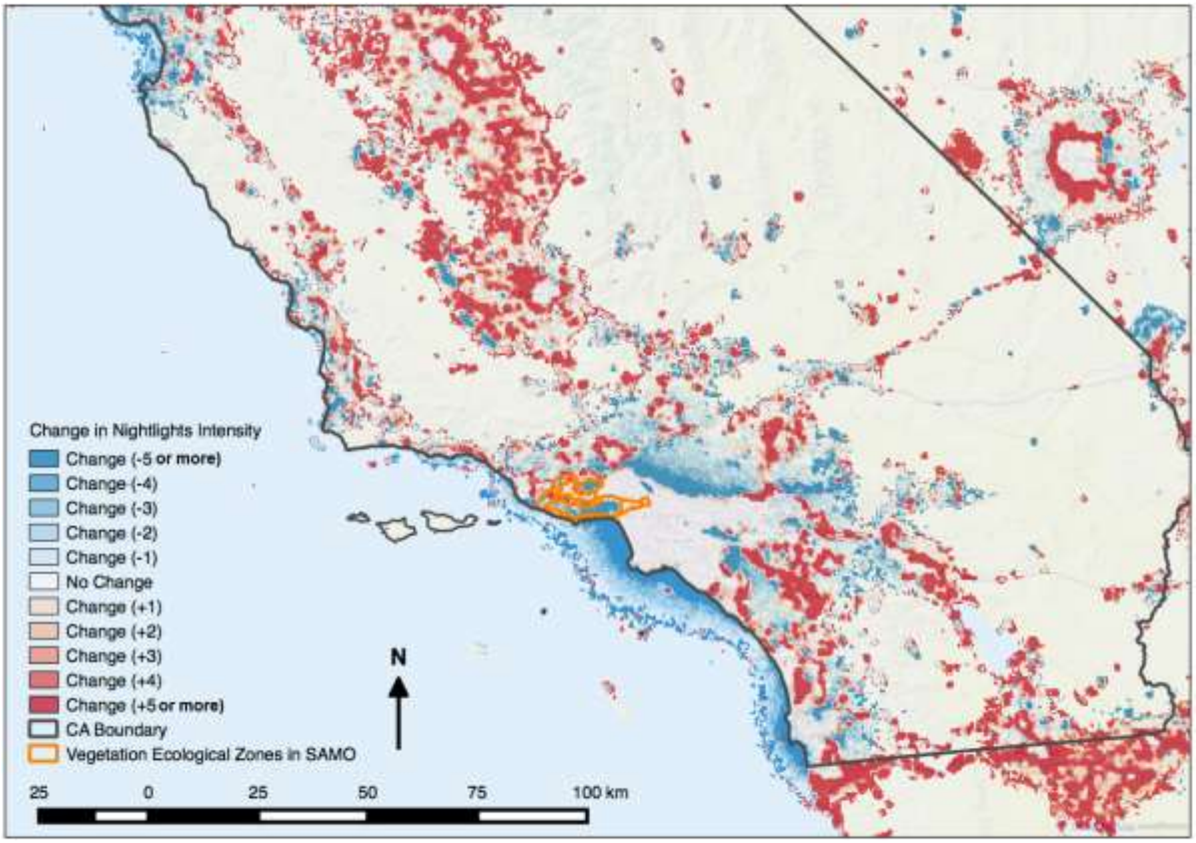

Figure 7. Regional perspective of nighttime lights and change in nighttime light intensity (digital number) from 1992 to 2012 for southern California.

Mediterranean Coast Network Park Units

Mean annual DN from uncalibrated data, and the annual mean, standard deviation, minimum and maximum DN calibrated according to Elvidge et al. (2014) are provided for all three parks in Appendix A. We use values from the uncalibrated data throughout this report. There was little difference in calibrated and uncalibrated data (Appendix A), and using uncalibrated data was the most standard and repeatable way to compare results for parks across the region and nation.

Santa Monica Mountains National Recreation Area

Santa Monica Mountains National Recreation Area (SAMO) management zone polygons (Figure 8) contained 1,753 DMSP pixels and have the highest DN of the three parks, with a mean brightness value using uncalibrated data of 39.9 and standard deviation of 20.6 from 2012 (Appendix A). This is the third highest brightness value among 59 national parks in the US (Appendix B). Zones of management interest (Figure 8) can be compared with nighttime light intensity (Figure 9) within the park.

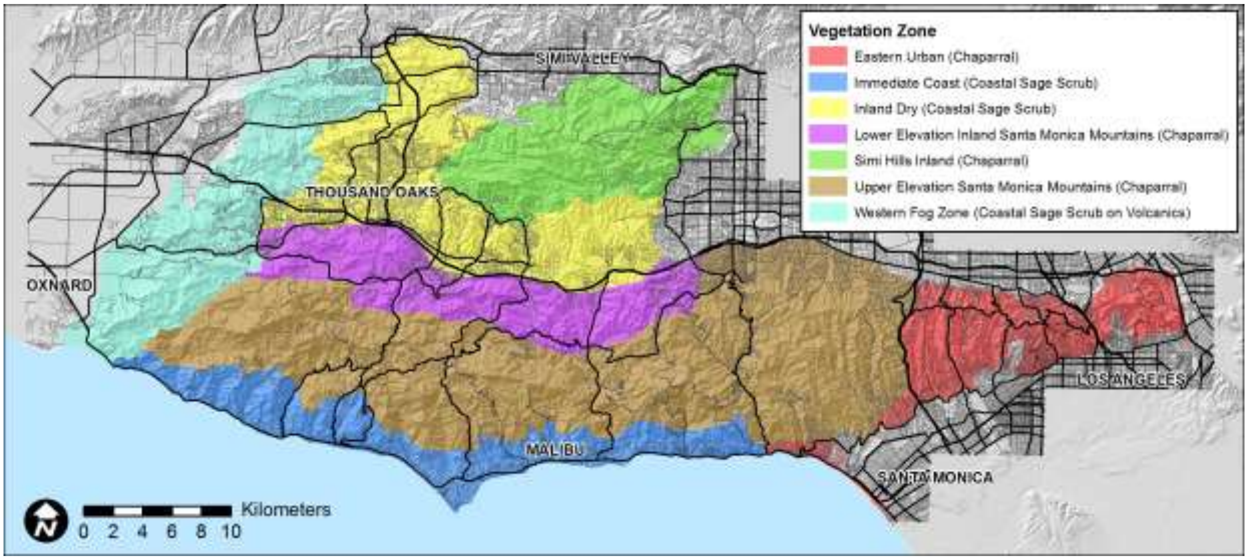

Figure 8. Major vegetation and management zones in the Santa Monica Mountains National Recreation Area.

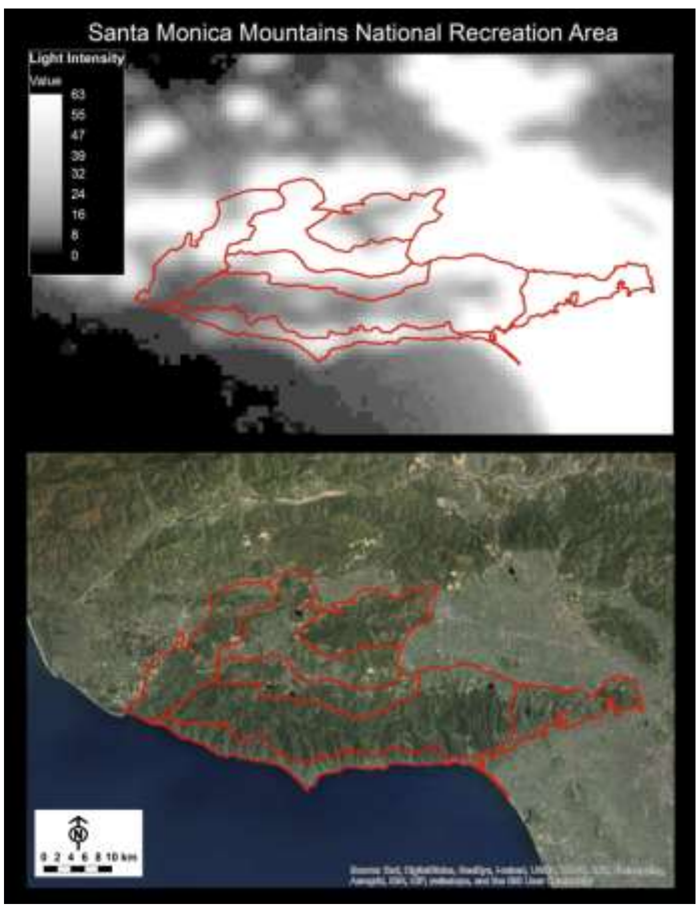

Figure 9. Nighttime light imagery (top) from 2012 and GIS management polygons (bottom) for SAMO.

We can see from comparing the images that the highest intensity of nighttime lights is located in developed and lower elevation areas (Figure 9). The mountainous regions have lower light intensity, but are nonetheless affected by the lights emitted from surrounding areas. All management zones in SAMO are impacted by nighttime light. Simi Valley Hill Inland, Western Fog Zone, and Upper Elevations Santa Monica Mountains are the least impacted zones. The Eastern Urban and Inland Dry areas are the most impacted. Indeed, the Eastern Urban zone has similar brightness values as the city of Los Angeles.

A time series of nighttime light intensity (DN) identifies changes in light pollution intensity from 1992 to 2012 (Figure 10). Nighttime light pollution has remained steady over SAMO, with a slight reduction since 1992.

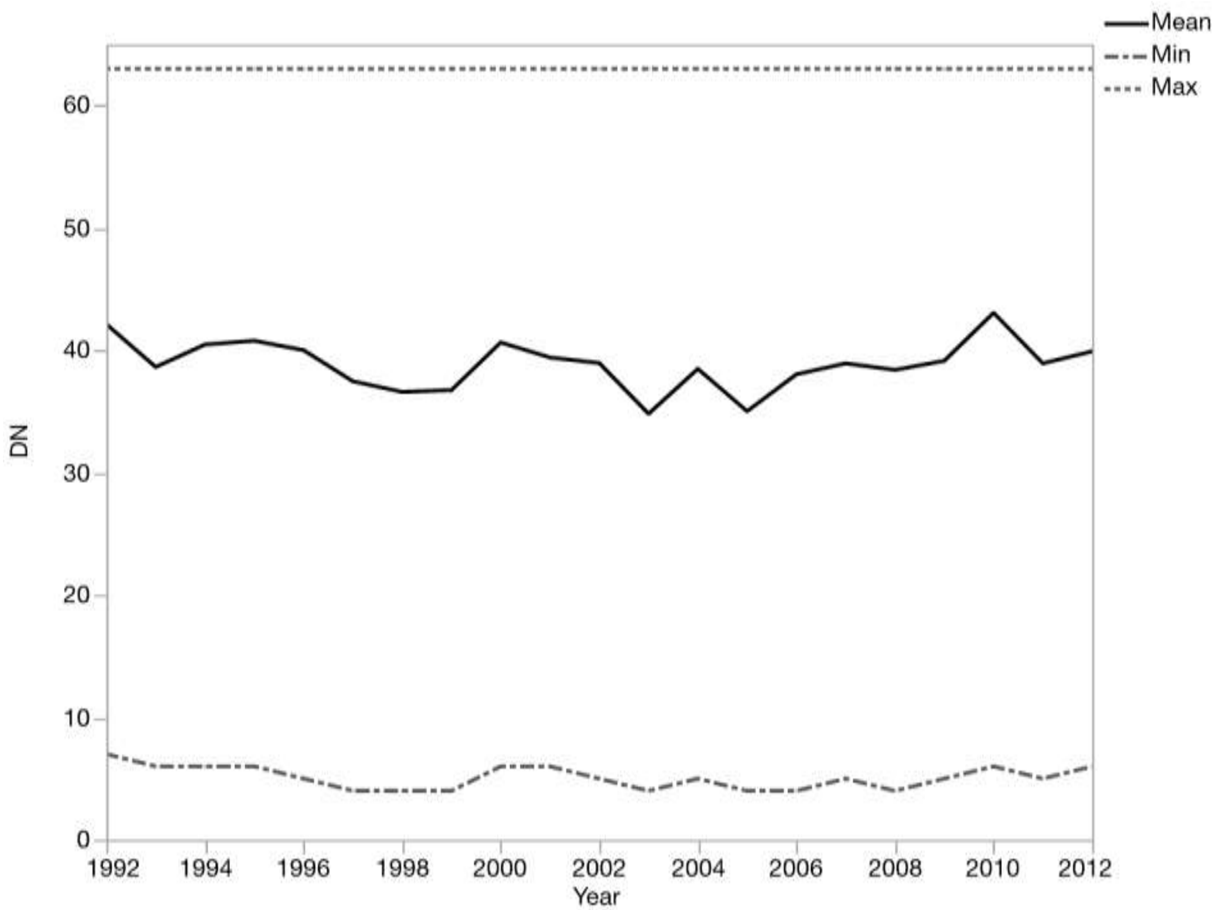

Figure 10. Changes in light pollution in SAMO from 1992 to 2012.

A change detection analysis of nighttime lights identified areas that have been impacted between 1992 and 2012 (Figure 11). This image shows that most of the change since 1992 has occurred in the western region of the park. In particular, the Western Fog Belt, Lower Elevation Inland Santa Monica Mountains, and Inland Dry Zones have experienced increases since 1992. The Eastern Urban

zone, which is already substantially urbanized, has the highest light pollution, with saturated digital number values (63) similar to the city of Los Angeles (Table 1).

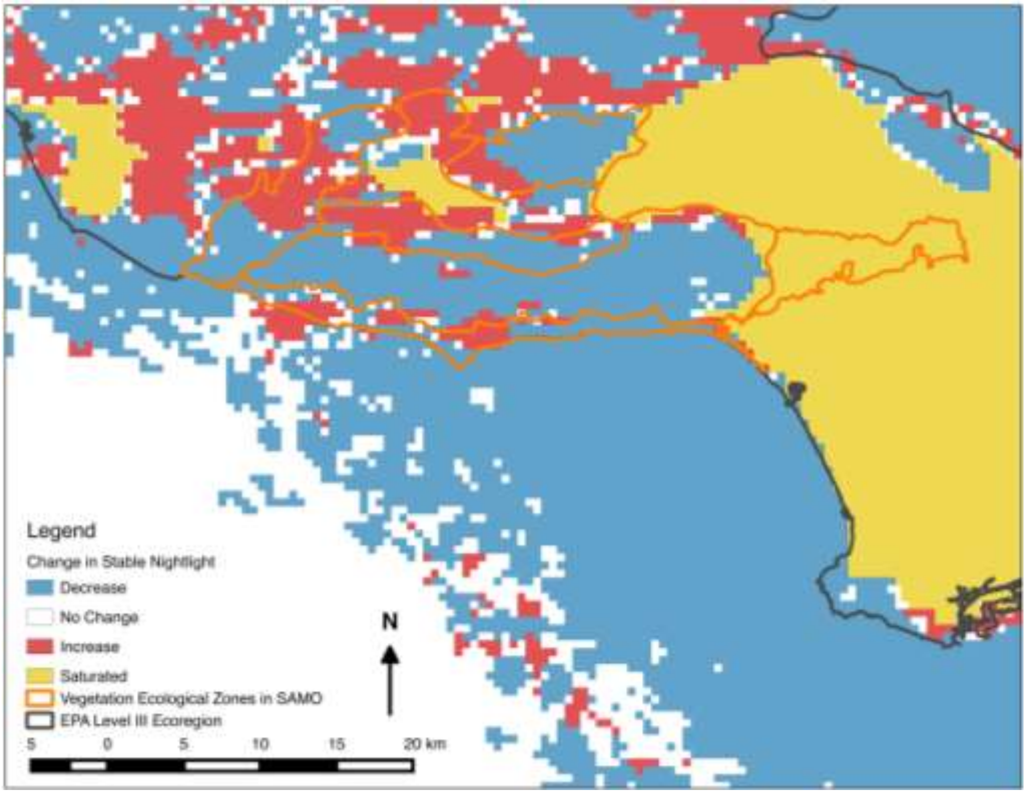

Figure 11. Changes in nighttime light brightness (blue = decrease, red = increase, white = no change, yellow = DN of 63 or saturated) from 1992 to 2012 over management zones in the Santa Monica Mountains National Recreation Area.

Table 1. Major vegetation and management zones in the Santa Monica Mountains National Recreation Area and mean and standard deviation of nighttime light brightness in 2012.

Zone	Mean	Standard Deviation
Western Fog Zone (Coastal Sage Scrub on Volcanics)	32.6	21.0
Immediate Coast (Coastal Sage Scrub)	25.7	15.3
Upper Elevation Santa Monica Mountains (Chaparral)	29.1	18.9
Lower Elevation Inland Santa Monica Mountains (Chaparral)	41.3	15.1
Inland Dry (Coastal Sage Scrub)	60.2	5.5
Simi Hills Inland (Chaparral)	43.9	15.6
Eastern Urban (Chaparral)	62.4	3.3

Channel Islands National Park

Channel Islands National Park (CHIS) contained 718 DMSP pixels and has very low light pollution, with brightness values below 1.0 every year from 1992 to 2012 (Appendix A). Indeed, by comparison, nighttime light pollution in CHIS is lower than in most of the 59 national parks, making this park one of the least light polluted parks in the NPS. (Figure 12; Appendix B).

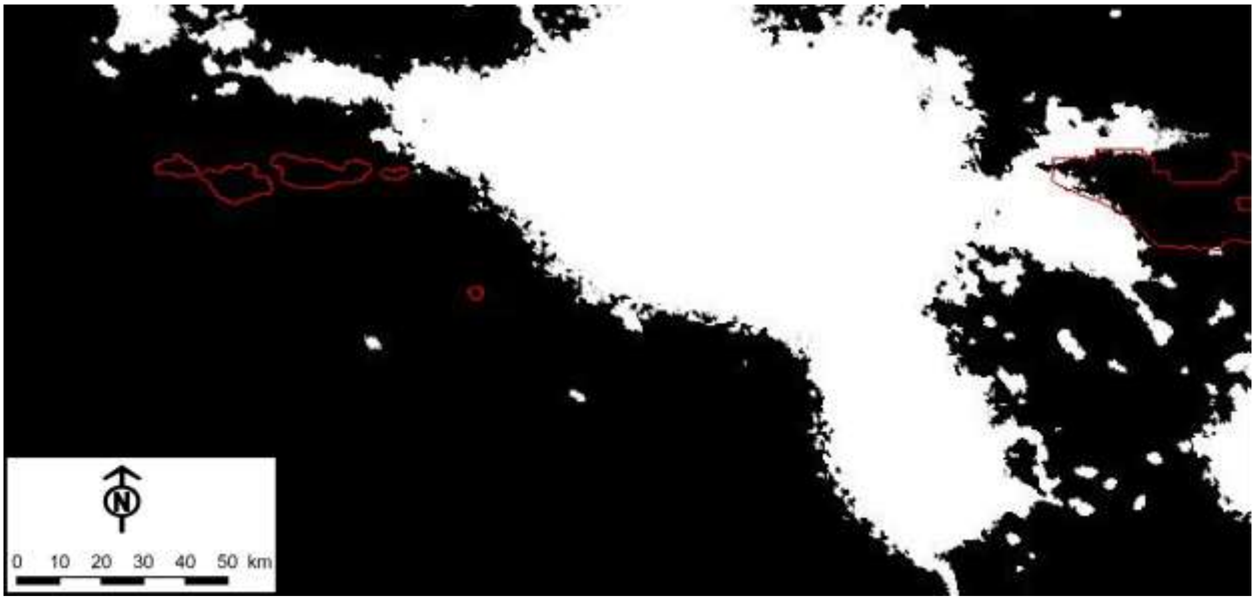

Figure 12. Nighttime light brightness in Channel Islands National Park (outlined in red) from 2012.

Nighttime light brightness in CHIS had a mean value of 0.06 (standard deviation 0.37) from 1992 to 2012 (Figure 13). There was a spike in nighttime light brightness in 1999 when nighttime light pollution increased to 0.68; all other years had mean values that were below 0.2. Channel Islands National Park is in the unique position that nighttime lights on the lands come from light sources over the ocean (e.g., squid fisherman) and not light sources on the islands (Figure 14).

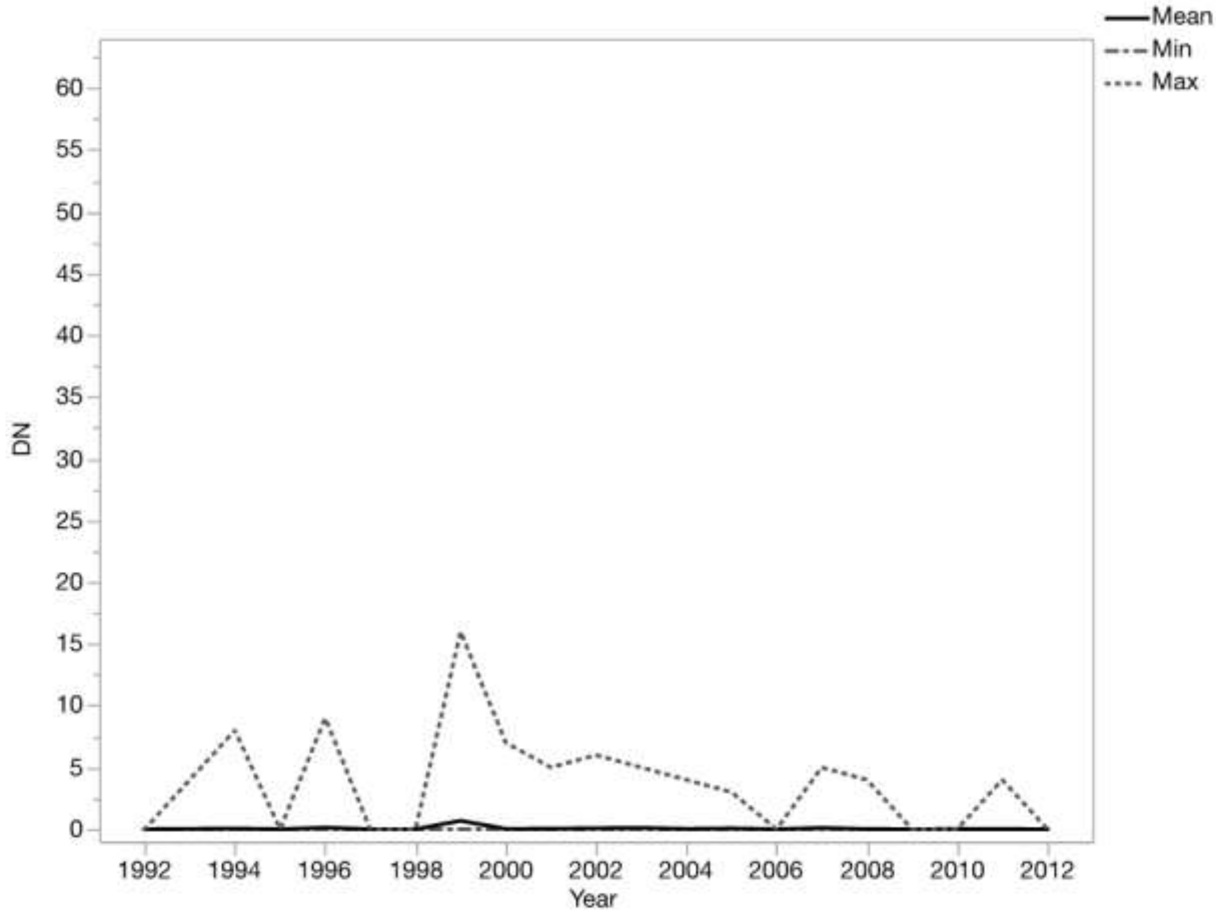

Figure 13. Nighttime light brightness (mean Digital Number) in CHIS from 1992 to 2012. Note that all mean and minimum values were less than 1.

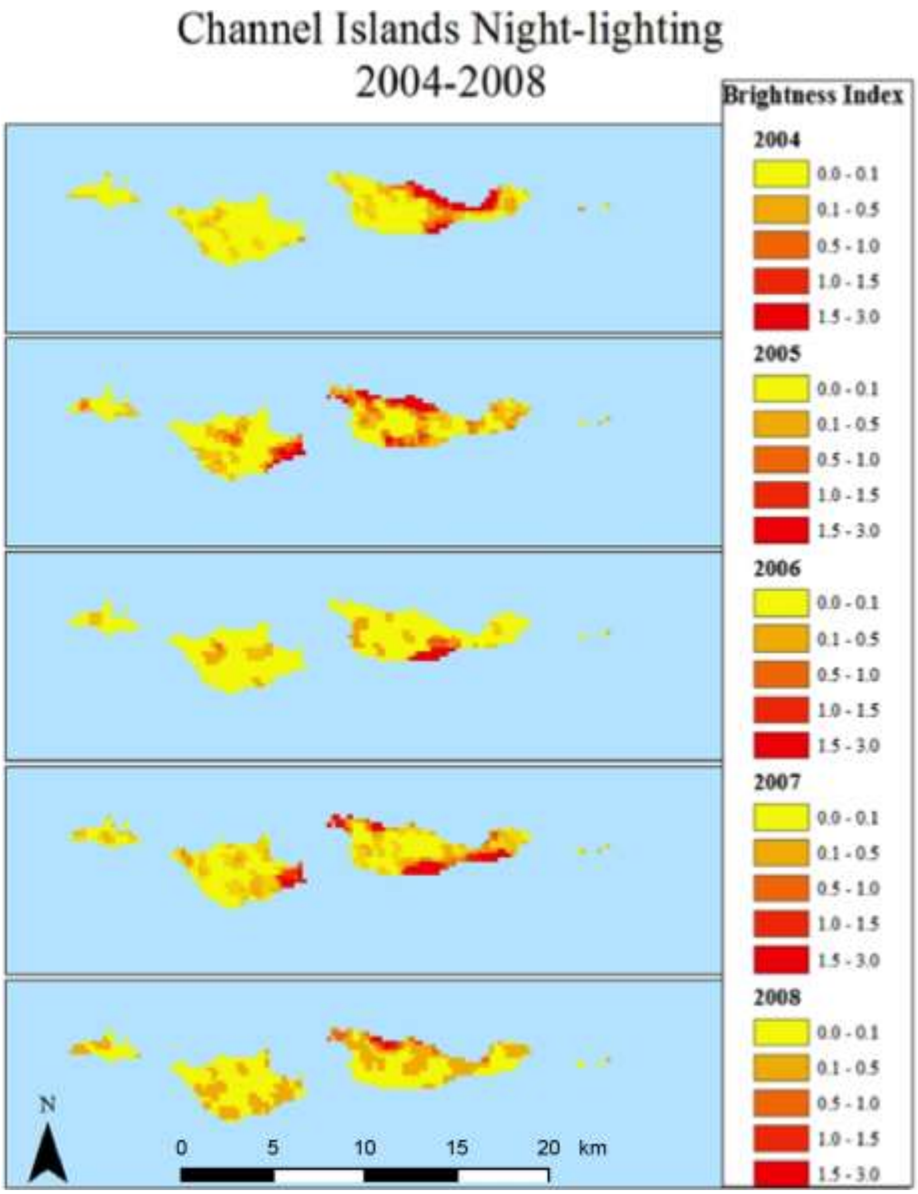

Figure 14. Map shows nighttime brightness values averaged over the four northern islands of CHIS, 2004–2008, from F16 DMSP satellite. Many of these shifts in areas of brightness over time are caused by the change in location of squid fishing boats present offshore.

Cabrillo National Monument

The intensity of nighttime light in Cabrillo National Monument (CABR) was similar to SAMO, with a mean brightness value of 27.7 (standard deviation 19.6) for 2012. We could only analyze a small number of DMSP pixels on land due to CABR's small size (Figure 15). However, a clean north–south gradient in light pollution can be seen, with the lowest nighttime light intensity in the south at Point Loma (DN = 7). There is clear evidence of a decline in DN in and around CABR (Figure 16). On average, the nighttime light intensity has declined since the 1990s.

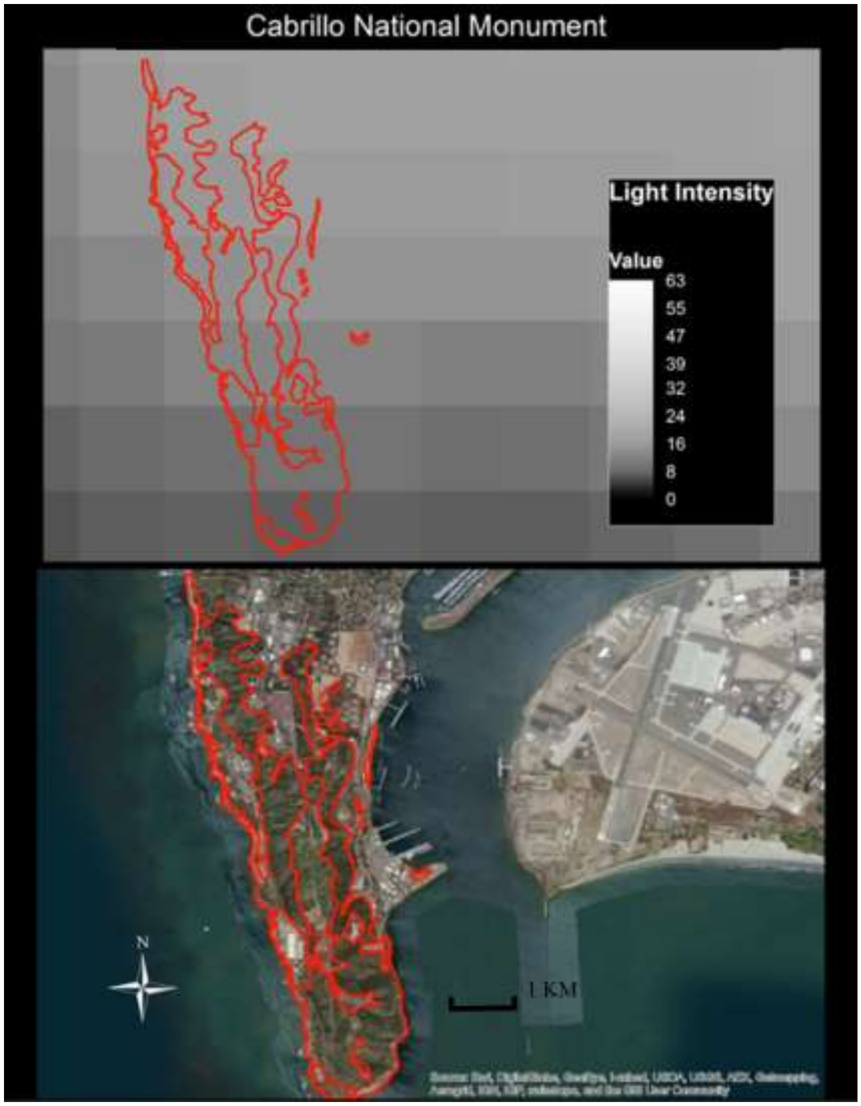

Figure 15. Nighttime light imagery from 2012 (top) and GIS vegetation polygons (bottom) of interest at CABR.

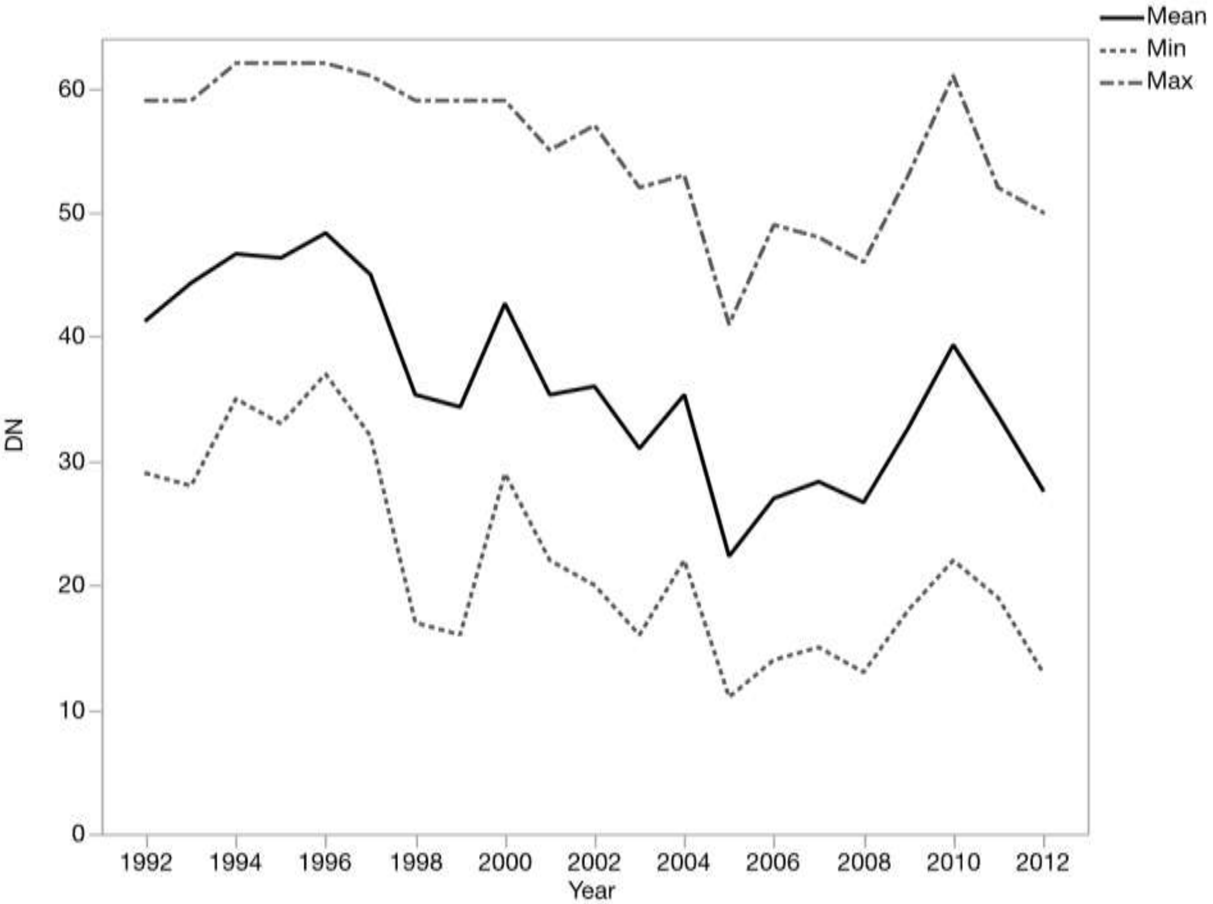

Figure 16. Changes in nighttime light pollution in CABR from 1992 to 2012.

Discussion

Nighttime lights have an impact on a number of national parks in the US (Appendix A and B). Bennie et al. (2014) established a threshold of change of +/- 3 DN units as denoting significant changes in brightness. We considered the more conservative value of +/- 5 DN units as denoting significant changes. Based on these thresholds, trends of nighttime lights can be viewed as steady or improving (a decrease in nighttime lights) within all three NPS protected areas in the Mediterranean Coast Network of southern California. Overall, nighttime lights since 1992 have been stable in SAMO, decreased in CABR, and remained extremely low in CHIS. Nighttime light intensity and change detection can identify priority zones for light abatement within parks and areas that should be monitored to ensure that there are no further increases. These zones can also be monitored in the future using updated and calibrated imagery to assess the effectiveness of education and light abatement programs (Bennie et al. 2014). Despite the stable or decreasing trends observed from within the parks of the MEDN, the parks remain significantly affected by the scattered light in the atmosphere from the surrounding regions that increases illumination and obscures the view of the night sky.

The brightness or DN values of approximately 40 at SAMO and 28 at CABR are very high compared to most other national parks. Only two national parks in the United States (Cuyahoga Valley National Park (40), Hot Springs National Park (46)) produce higher brightness values than SAMO and CABR. We did not compare against other types of national park units, such as recreation areas or monuments. Planning and mitigation measures should be initiated in partnership with surrounding land owners to reduce light pollution within the parks.

Santa Monica Mountains National Recreation Area

Annual analyses in SAMO reveal that select locations are still experiencing increases in brightness and these should be investigated to ensure they are in compliance with local nighttime light ordinances in Ventura and Los Angeles Counties. SAMO includes two areas that have important lighting policies. The Local Coastal Plan for the City of Malibu includes restrictions on lighting that have been in place since 2002. Additional portions of the recreation area are covered by policies of the County of Los Angeles, which also restrict lighting, but have done so for shorter periods. The southern portion of SAMO generally has more stringent controls on development, which is consistent with the general pattern of changes in nighttime lights. Our analysis identifies priority zones for light abatement and areas that should be monitored to ensure that there are no further increases. These zones can also hypothetically be monitored in the future using updated DMSP imagery to assess the effectiveness of education and light abatement programs.

Channel Islands National Park

There has been no substantial change in lighting within CHIS. Indeed, there are very few light sources on the Channel Islands. However, intense offshore fishing appears to have an impact on brightness values over the islands (California Fisheries Fund 2008). Nighttime light imagery identifies minor changes in lighting that appear to emanate from commercial fishing fleets that use artificial light to attract species such as squid off the coast of CHIS. Light from these commercial fishing fleets appears to have impacted slopes on the north and south side of the Channel Islands. Data from

commercial squid catches in California suggest that the increase in mean brightness levels in 1999 and other periodic increases in the maximum brightness values (Figure 13) may be due to increased squid fishing around the Channel Islands during this time (California Fisheries Fund 2008) (Figure 17).

Artificial lights may cause severe ecological perturbation to seabirds because fledglings are attracted to lights at night and may become injured, grounded or entrapped by lights (Ogden 1996, Montevecchi 2006), and therefore become vulnerable to exhaustion and predation (Rodriguez et al. 2014). Nighttime lighting may also affect the choice of nesting sites (De Molenaar et al. 2000). The Channel Islands are vital habitat for seabirds and shorebirds, providing essential nesting and feeding grounds for most seabirds in southern California. Twelve species of seabirds depend on the rich marine resources and isolation of the islands to provide food and undisturbed nesting grounds safe from predators. Even low levels of nighttime lighting may affect the nesting habitat and reproductive success of seabirds. Efforts to minimize light pollution and educate boaters on this issue should continue.

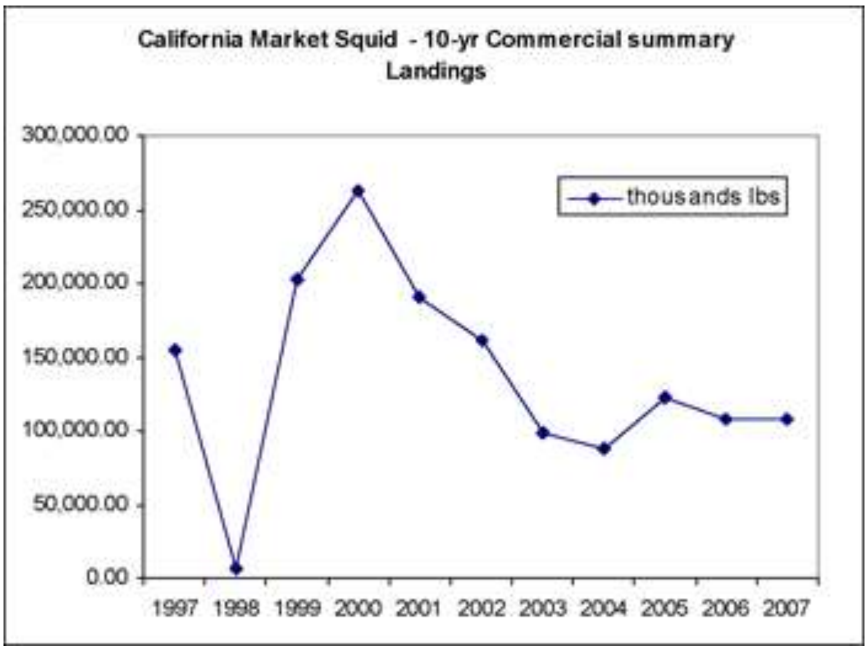

Figure 17. Summary of 11-year commercial squid catch from California Fisheries Fund (2008).

Cabrillo National Monument

Overall, light pollution in CABR has been reduced since 1992. The periodic spikes in light pollution may to be correlated with the decommissioning and commissioning of naval facilities on federal land around CABR. In 1997 a San Diego facility north of the monument became the headquarters of the Navy's Space and Naval Warfare Systems Command and changes in nighttime light brightness at CABR may be due to energy use or lighting technology at this facility. The southern tip of the park is the darkest area and therefore is the best location to view night skies in the park. The close proximity of CABR to a large urban center makes it an ideal place to conduct educational programs regarding the importance of dark skies.

Limitations of DMSP products

There are a number of limitations that should be highlighted when using DMSP products. Nighttime lights measured via satellite provide a measure of where the lights are on the landscape and some of the bleed around them. Using DMSP does not allow us to measure the propagation of light in the atmosphere that affects artificial night sky brightness. To obtain that, which is generally considered light pollution from an astronomical perspective, requires the use of upward radiance plus mathematical models that show how light affects the area around it, even at significant distances. Our study quantifies the brightness and location of lights visible from above—and not the much more difficult to estimate contribution of those lights to artificial sky brightness. Lights visible from space are important for ecological reasons, and qualifying the direct glare from them provides useful information for park managers.

Another important clarification is that a reduction in the DN numbers or the radiance cannot always be related to a direct reduction in light pollution, and can be related to a change in the illumination technology (Bennie et al. 2014). Indeed, it is possible to have the same illumination but increased light pollution (Pawson and Bader 2014). Thus, a reduction in the DMSP radiance cannot always be viewed as a reduction of the light pollution, and field data may be needed to confirm it. Second, the DMSP data are not sensitive to changes in light pollution in saturated areas (DN = 63), like the eastern Santa Monica Mountains. Thus it is not possible to identify increases in nighttime lights in these regions. Finally, there may be issues with the impacts of coastal fog over southern California, especially for the Channel Islands, that should be investigated in the future to insure that the 1992 baseline data was not impacted by fog that has the potential to increase the radiance values from DMSP products over the water.

Additional methods for monitoring nighttime light

It is important to identify other standard monitoring practices that could also be used in the future. Individual pixel data from DMSP can be used to monitor areas of interest. This can be used to monitor changes in nighttime lights due to development or light abatement programs. Recent Visible Infrared Imaging Radiometer Suite (VIIRS) nighttime light imagery provides spaceborne imagery at a higher temporal resolution than DMSP. The Suomi National Polar-orbiting Partnership (Suomi NPP) is a new generation of satellites operated by NOAA intended to replace the Earth Observing System satellites that were launched from 1997 to 2011. The satellite orbits the Earth approximately 14 times a day and collects nighttime light data from the Visible Infrared Imaging Radiometer Suite (VIIRS) sensor, which has a 22-band radiometer. This sensor collects infrared and visible light data to observe wildfires, movement of ice, and changes in landforms (Raytheon 2014). However, it can be used to monitor daily, weekly, and monthly changes in nighttime lights under cloud free conditions. Indeed, this new sensor is able to identify the change in nighttime light due to the increase in Christmas or holiday lighting in southern California (National Aeronautics and Space Administration 2014; Figure 18).

Annual nighttime light assessments using DMSP are possible since 1992 and can be used as a baseline for all protected areas in the world (Gillespie, Willis, et al. 2014). In order to highlight the importance of night skies to park managers and best prepare to mitigate light pollution, this should be a

standard practice for all national park units in the US (Appendix B). Light pollution data can be collected for all NPS stewardship areas and annually compared for assessment of management practices. This landscape level approach could supplement the localized measurements being implemented by the NPS Night Skies Program. The use of VIIRS data modeled by Falchi et al.

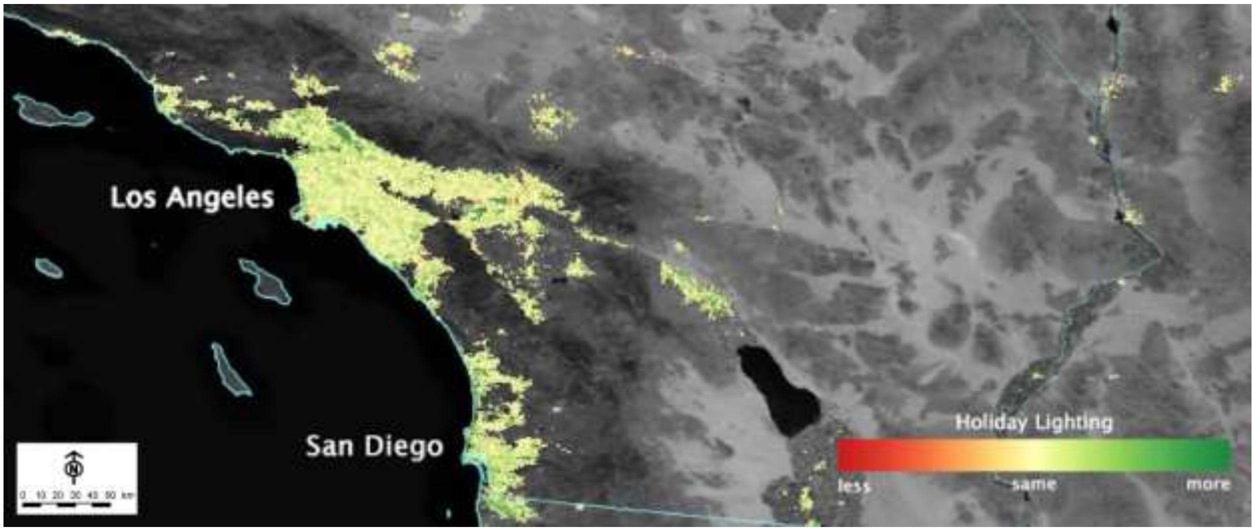

Figure 18. Increases in holiday lighting based on daily data from the NASA-NOAA Suomi NPP satellite for southern California. NASA's Earth Observatory/Jesse Allen.

(2015) and used by the NPS Natural Sounds and Night Skies Division (NSNSD) can continue to provide landscape scale data on a more frequent and higher resolution scale than the methodology used in this report, but only for timelines after 2012. The approach presented here (DMSP) is low to no cost due to the free nature of the data and the cooperation between the NPS and UCLA.

Field based sensors have been developed that quantify light pollution in one location and collect an all-sky image of the night sky for the measurement period, providing incredibly high resolution data (Figure 19). The images taken by the NPS Night Sky Team are especially effective at displaying the effects of light pollution and conversely, the benefits of dark skies. These field based sensors could be used at high priority areas to monitor change in nighttime light imagery, but are impractical for monitoring multiple large landscapes. Using long term nighttime light data with a 1992 baseline for DMSP and short-term nighttime light data from VIIRS might be the best approach for monitoring over large areas. The DMSP data should be used to monitor long term changes in light distribution and intensity. This can be done annually and compared to the 1992 baseline. VIIRS data can be used to show changes in light distribution and density over different times of the year and can be used to test whether policy or ordinance changes have an impact on light pollution.

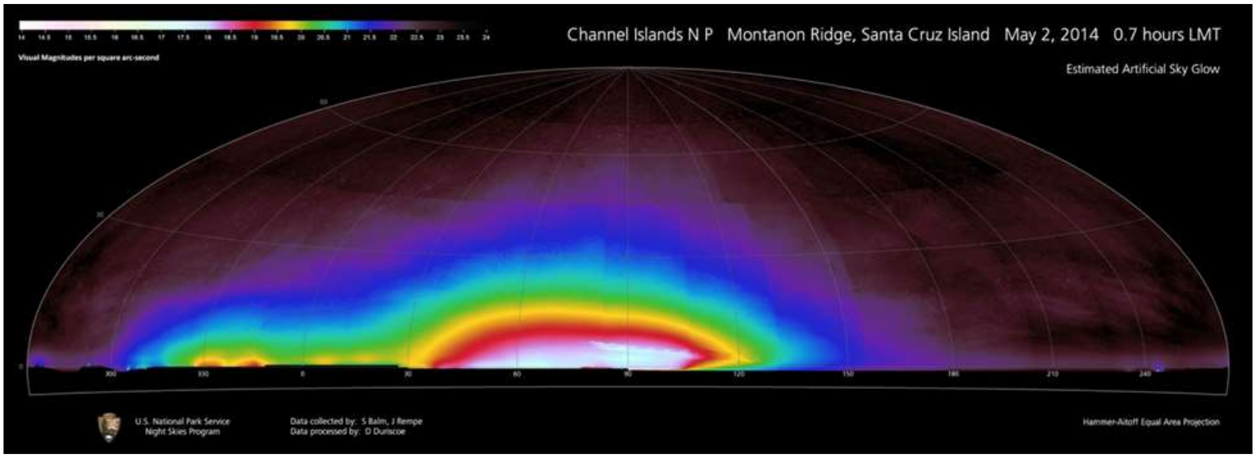

Figure 19. Results of a research-grade digital camera used to capture nighttime lights across the entire sky from the Channels Islands National Park, California. The image shows Ventura county nighttime lights in white and red in the East and dark skies to the West.

Management implications

There are multiple ways park managers can work to reduce ecological light pollution near public lands. Although the intensity of nighttime lights has been stable or reduced in many areas of southern California national park units, there are methods that have been used to conserve dark skies in regions of Europe that can also be used in southern California (Evers 2013; Bennie et al. 2014). Further measures at the street light level (covers, wattage), and parcel level (outside lighting regulations, installation of amber or intelligent LEDs) should continue. The NSNSD suggests these six sustainable outdoor lighting principles: 1) light only if you need it, 2) light only when you need it, 3) light only where you need it, 4) use appropriate color spectra, 5) use the minimum amount of light necessary, 6) choose energy efficient lamps and fixtures. Significant nighttime light ordinances put in place by cities and counties can be monitored to examine the impact of these ordinances. This baseline report can provide natural resource managers with regions that have experienced a 5% increase in nighttime light over time and identify areas where light abatement should be focused. The GIS files from this report are available from the NPS Inventory and Monitoring Program and should allow managers to examine specific areas.

Park managers at CHIS and SAMO are interested in pursuing International Dark Sky Park certification for their parks (http://darksky.org/idsp/parks/). With this goal in mind, night skies should be protected, particularly in the least impacted areas within SAMO: the Simi Valley Hill Inland Zone, Western Fog Zone, and Upper Elevations of the Santa Monica Mountains. These are ideal locations for visitors to see dark skies. These areas are also within an hour drive for five million people who might be interested in observing the night sky with fewer impacts from light pollution. Education programs concerning the importance of dark skies could be undertaken in high priority areas and the region in general. Ideally the timing of such programs should coincide with lunar cycles, weather conditions, and time of year. Indeed, the best time to see dark skies in the NPS area is during new moon conditions in December and January (e.g., December 11, 2015). These might be ideal times to discuss nighttime light issues with the general public and provide education materials about the importance of reducing light pollution and the benefits of saving energy and dark skies. The effective-

ness of such programs then can be quantified by brightness changes using field measurements and spaceborne sensors for each park and management area (e.g., Simi Valley Inland).

References

Agnew, J., T. W. Gillespie, J. Gonzalez, and B. Min. 2008. Baghdad nights: Evaluating the US military "surge" using nighttime light signatures. Environment and Planning A 40:2285–2295.

Aubé, M., J. Roby, and M. Kocifaj. 2013. Evaluating potential spectral impacts of various artificial lights on melatonin suppression, photosynthesis, and star visibility. PLoS ONE 8:e67798.

Aubrecht, C., C. D. Elvidge, T. Longcore, C. Rich, J. Safran, A. E. Strong, C. M. Eakin, K. E. Baugh, B. T. Tuttle, A. T. Howard, and E. H. Erwin. 2008. A global inventory of coral reef stressors based on satellite observed nighttime lights. Geocarto International 23:467–479.

Barbour, M., T. Keeler-Wolf, and A. A. Schoenherr, eds. 2007. Terrestrial Vegetation of California. 3rd edition. California Department of Fish and Game, University of California Press, Berkeley.

Bennie, J., T. W. Davies, J. P. Duffy, R. Inger, and K. J. Gaston. 2014. Contrasting trends in light pollution across Europe based on satellite observed night time lights. Scientific Reports 4:3789.

California Fisheries Fund. 2008. California Fisheries Atlas - California Market Squid. http://www.californiafisheriesfund.org/reso_atlas_squid.html.

Cameron, L., R. Sauvajot, and D. Kamradt. 2005. Mediterranean Coast Network – Vital Signs monitoring plan. National Park Service Unpublished Report, Thousand Oaks, California.

Cinzano, P., F. Falchi, and C. D. Elvidge. 2001. The first world atlas of the artificial night sky brightness. Monthly Notices of the Royal Astronomical Society 328:689–707.

Davies, T. W., J. P. Duffy, J. Bennie, and K. J. Gaston. 2014. The nature, extent, and ecological implications of marine light pollution. Frontiers in Ecology and the Environment 12:347–355.

Defense Meteorological Satellite Program (DMSP). 2012. DMSP Data Download: Nighttime Lights of the World - Change Pair (Version 4). http://www.ngdc.noaa.gov/eog/.

De Molenaar J.G., D.A. Jonkers and M.E. Sanders. 2000. Road illumination and nature. III. Local influence of road lights on a black-tailed godwits (*Limosa l limosa*) population. Wageningen, The Netherlands: Alterra.

Doll, C. N. H, J-P. Muller, and J. G. Morley. 2006. Mapping regional economic activity from nighttime light satellite imagery. Ecological Economics 57:75–92.

Elvidge, C. D., K. E. Baugh, E. A. Kihn, H. W. Kroehl, and E. R. Davis. 1997. Relation between satellite observed visible-near infrared emissions, population, and economic activity. International Journal of Remote Sensing 18:1373–1379.

Elvidge, C. D., F. C. Hsu, K. E. Baugh, and T. Ghosh. 2014. National trends in satellite-observed lighting. Global Urban Monitoring and Assessment through Earth Observation 23:97–118.

Engle D. L., and J. L. Largier. 2006. Assessment of coastal water resources and watershed conditions at Cabrillo National Monument, California. Natural Resources Technical Report NPS/NRWRD/NRTR—2006/355. https://www.nature.nps.gov/water/nrca/assets/docs/cabr_coastal.pdf.

Evers, M. 2013. A brighter, dimmer future: Germany's saviors of the night. http://www.spiegel.de/international/germany/ambitious-efforts-to-reduce-light-pollution-in-germany-and-elsewhere-a-932352.html.

Falchi, F., P. Cinzano, C. Kyba, and B. A. Portnov. 2015. The New World Atlas of Artificial Sky Brightness. IAU General Assembly 22:47038.

Fancy, S. G., J. E. Gross, and S. L. Carter. 2009. Monitoring the condition of natural resources in U.S. National Parks. Environmental Monitoring and Assessment 151:161–174.

Gaston, K. J., J. Bennie, T. W. Davies, and J. Hopkins. 2013. The ecological impacts of nighttime light pollution: a mechanistic appraisal. Biological Reviews 88:912–927.

Gauthreaux, S.A., and C. G. Belser. 2006. Effects of artificial night lighting on migrating birds. Pages 67–93 in C. Rich and T. Longcore, editors. Ecological Consequences of Artificial Night Lighting. Island Press, Washington, D.C.

Gillespie, T.W., E. Frankenberg, K. Fung Chum, and D. Thomas. 2014. Night-time lights time series of tsunami damage, recovery, and economic metrics in Sumatra, Indonesia. Remote Sensing Letters 5:286–294.

Gillespie, T.W., K. Willis, and S. Ostermann-Kelm. 2014. Spaceborne remote sensing of the world’s protected areas. Progress in Physical Geography 39:88–404.

Grimm, N. B., S. H. Faeth, N. E. Golubiewski, C. L. Redman, J. G. Wu, X. M. Bai, and J. M. Briggs. 2008. Global change and the ecology of cities. Science 319:756–760.

Grimm, N. B., D. Foster, P. Groffman, J. M. Grove, C. S. Hopkinson, K. J. Nadelhoffer, D. E. Pataki, and D. P. C. Peters. 2008. The changing landscape: Ecosystem responses to urbanization and pollution across climatic and societal gradients. Frontiers in Ecology and the Environment 6:264–272.

Hölker, F., C. Wolter, E. K. Perkin, and K. Tockner. 2010. Light pollution as a biodiversity threat. Trends in Ecology and Evolution 25:681–682.

Kerr, J. T., and M. Ostrovsky. 2003. From space to species: ecological applications for remote sensing. Trends in Ecology and Evolution 18:299–305.

Longcore, T., and C. Rich. 2004. Ecological light pollution. Frontiers in Ecology and the Environment 2:191–198.

Montevecchi, W. A. 2006. Influences of artificial light on marine birds. Pages 94–113 *in* C. Rich and T. Longcore, editors. Ecological Consequences of Artificial Night Lighting. Island Press, Washington, D.C.

National Aeronautics and Space Administration (NASA). 2014. NOAA/NASA satellite sees holiday lights brighten cities. http://www.nasa.gov/content/goddard/satellite-sees-holiday-lights-brighten-cities.

National Park Service (NPS). 2005. Mediterranean Coast Network – Vital Signs Monitoring Plan. Unpublished report. National Park Service, Thousand Oaks, California.

National Park Service (NPS). 2014. Night Sky. http://www.nature.nps.gov/night/index.cfm.

Ogden, L. J. E. 1996. Collision course: the hazards of lighted structures and windows to migrating birds. Toronto, Canada: World Wildlife Fund Canada and Fatal Light Awareness Program.

Pawson, S. M., and M. F. Bader. 2014. LED lighting increases the ecological impact of light pollution irrespective of color temperature. Ecological Applications 24:1561–1568.

Perry, G., Buchanan, B.W., Fisher, R.N., Salmon, M., and S.E. Wise. 2008. Effects of artificial night lighting on amphibians and reptiles in urban environments. Herpetological Conservation 3:239–256.

Raytheon. 2014. Visible Infrared Imaging Radiometer Suite (VIIRS). http://www.raytheon.com/capabilities/products/viirs/.

Rich, C., and T. Longcore, eds. 2006. Ecological Consequences of Artificial Night Lighting. Island Press, Washington, D.C.

Rodriguez, A. G. Burgan, P. Dann, R. Jessop, J. J. Negro, and A. Chiaradia. 2014. Fatal attraction of short-tailed shearwaters to artificial lights. PLOS ONE 9:e1101114.

Small C., F. Pozzi, and C. D. Elvidge. 2005. Spatial analysis of global urban extent from DMSP-OLS night lights. Remote Sensing of Environment 96:277–291.

Underwood, E. C., J. H. Viers, K. R. Klausmeyer, R. L. Cox, and M. R. Shaw. 2009. Threats and biodiversity in the Mediterranean biome. Diversity and Distributions 15:188–197.

Willis, K. S., S. Ostermann-Kelm, L. Lee, T. W. Gillespie, G. M. MacDonald, and F. Federico. In review. Monitoring landscape dynamics in the Mediterranean Coast Inventory and Monitoring Network of Southern California. Natural Resource Report. National Park Service, Fort Collins, Colorado.

Appendix A. Mean, Standard Deviation (SD), Minimum (Min), and Maximum (Max) Nighttime Light Brightness in Digital Number from 1992 to 2012 for Santa Monica Mountains National Recreation Area, Channel Islands National Park, and Cabrillo National Monument.

Mean digital number from uncalibrated data, and mean, SD, min and max for digital numbers following the calibration methods of Elvidge et al. (2014).

Table A-1. Santa Monica Mountains National Recreation Area (SAMO, 1753 Pixels).

Year	Mean	SD	Min	Max	Mean (Calibrated)	SD (Calibrated)	Min (Calibrated)	Max* (Calibrated)
1992	42.12664	19.298719	7	63	34.30399	19.05346	8.6341	62.4109
1993	38.637764	20.068788	6	63	30.57212	18.58834	8.1968	62.723
1994	40.471192	19.373386	6	63	29.5583	18.60242	6.8887	61.9423
1995	40.775813	19.710156	6	63	29.25182	18.375	7.1875	62.3122
1996	40.010268	19.484009	5	63	29.80253	18.53343	6.1676	63
1997	37.473474	21.14363	4	63	29.37126	19.24508	5.4939	63
1998	36.602966	21.75302	4	63	28.18404	19.47865	6.1751	62.54369
1999	36.752995	21.155033	4	63	27.86466	19.21144	6	63
2000	40.644039	19.867367	6	63	26.65433	17.92594	6.3606	62.004
2001	39.411865	20.042031	6	63	26.55907	18.63512	5.903	63
2002	38.958928	20.660816	5	63	24.69327	18.81673	4.8581	63
2003	34.816885	21.313144	4	63	25.63621	19.05931	5.6414	63
2004	38.483742	20.9679	5	63	24.16578	18.21788	4.5297	63
2005	35.021677	21.139097	4	63	24.88298	18.63244	5.5627	63
2006	38.036509	20.832607	4	63	25.1456	18.55101	5.8765	63
2007	38.934969	20.900894	5	63	24.26386	18.77758	5.2314	63
2008	38.401597	20.606546	4	63	24.85349	18.61857	4.5288	63
2009	39.13919	20.658398	5	63	24.9448	17.36327	6.2507	61.90171
2010	43.068454	19.524656	6	63	24.21342	17.64603	5.6382	60.2841
2011	38.933828	20.712733	5	63	21.76506	16.58649	5.6431	60.0761
2012	39.908157	20.638526	6	63	23.26433	18.40629	5.784	61.5927

* Some max DN values inside SAMO did not have a value at 63 (saturation value of DMSP-OLS sensors) because of the data manipulation included in the calibration method.

Table A-2. Channel Islands National Park (CHIS, 718 Pixels).

Year	Mean	SD	Min	Max	Mean (Calibrated)	SD (Calibrated)	Min (Calibrated)	Max (Calibrated)
1992	0	0	0	0	0	0	0	0
1993	0.027855	0.332865	0	4	0.057624	0.543628	0	5.1862
1994	0.044568	0.47028	0	8	0	0	0	0
1995	0	0	0	0	0	0	0	0
1996	0.118384	0.805263	0	9	0	0	0	0
1997	0	0	0	0	0	0	0	0
1998	0	0	0	0	0	0	0	0
1999	0.679666	2.42325	0	16	0.231111	1.819624	0	18
2000	0.02507	0.390881	0	7	0.030563	0.458719	0	7.3928
2001	0.036212	0.397093	0	5	0	0	0	0
2002	0.066852	0.523894	0	6	0.095163	0.614809	0	5.8259
2003	0.094708	0.568293	0	5	0	0	0	0
2004	0.020891	0.281178	0	4	0	0	0	0
2005	0.057103	0.406809	0	3	0.006237	0.132153	0	2.8065
2006	0	0	0	0	0	0	0	0
2007	0.0961	0.576588	0	5	0.128587	0.673911	0	4.3074
2008	0.009749	0.186473	0	4	0	0	0	0
2009	0	0	0	0	0	0	0	0
2010	0.008357	0.158223	0	0	0	0	0	0
2011	0.009749	0.186473	0	4	0.020017	0.300645	0	4.8816
2012	0	0	0	0	0	0	0	0

Table A-3. Cabrillo National Monument (CABR, 3 Pixels).

Year	Mean	SD	Min	Max	Mean (Calibrated)	SD (Calibrated)	Min (Calibrated)	Max (Calibrated)
1992	41.33333	15.69501	29	59	40.80165	6.741018	30.9262	43.5298
1993	44.33333	15.567059	28	59	49.2123	9.657774	35.3162	52.0328
1994	46.66666	13.868429	35	62	40.66525	4.188672	34.0279	42.9262
1995	46.33333	14.640128	33	62	43.63229	8.663287	29.3415	46.6809
1996	48.333333	12.66228	37	62	46.57722	8.04853	34.4851	49.98429
1997	45	14.73092	32	61	46.85078	7.718841	35.7171	50.2311
1998	35.333333	21.501938	17	59	37.66108	9.441634	24.6351	41.6931
1999	34.333333	22.188586	16	59	32.36552	5.558233	23	35
2000	42.666667	15.176737	29	59	37.85626	6.018787	28.607	40.3334
2001	35.333333	17.387735	22	55	30.27092	4.846199	23.095	32.4955
2002	36	19	20	57	26.69514	6.347169	16.6037	29.6531
2003	31	18.734994	16	52	25.01223	8.394978	12.755	30.3166
2004	35.333333	15.947832	22	53	27.13061	6.605017	17.0487	30.7251
2005	22.333333	16.289056	11	41	18.26276	3.035089	13.5289	19.8209
2006	27	19.157244	14	49	22.46099	4.594569	15.5837	25.877
2007	28.333333	17.387735	15	48	19.10149	4.069738	12.7242	21.3678
2008	26.666667	17.214335	13	46	19.46538	4.025822	13.4667	21.4115
2009	32.666667	18.175075	18	53	25.9983	5.030388	18.6479	28.6269
2010	39.333333	19.857828	22	61	24.45406	6.633302	14.3833	28.1625
2011	33.666667	16.802778	19	52	24.26421	5.623004	16.0886	26.6306
2012	27.666667	19.655364	13	50	14.92787	2.748061	10.8177	16.361

Appendix B. Nighttime Light Brightness in Digital Number in National Parks from 1992 to 2012.

Name	Pixels	1992 Mean	1992 SD	2012 Mean	2012 SD	Change 1992 to 2012
Acadia	292	3.263	4.645	3.575	4.077	0.311
Arches	450	0.455	2.071	0.8	3.238	0.344
Badlands	1587	0.037	0.497	0.027	0.422	-0.009
Big Bend	4421	0	0	0	0	0
Biscayne	926	6.541	5.345	7.248	6.149	0.707
Black Canyon of the Gunnison	131	0	0	0	0	0
Bryce Canyon	214	0.136	0.900	0.710	2.142	0.573
Canyonlands	2004	0	0	0	0	0
Capitol Reef	1469	0	0	0.003	0.130	0.003
Carlsbad Caverns	254	0.598	2.772	0.283	1.231	-0.314
Channel Islands	1389	0	0	0	0	0
Congaree Swamp	128	2.054	2.418	3.843	2.793	1.789
Crater Lake	1150	0	0	0	0	0
Cuyahoga Valley	211	40.127	11.663	40.412	11.328	0.284
Death Valley	19991	0.009	0.263	0.008	0.206	-0.001
Denali	62820	0.001	0.125	0.001	0.081	-0.001
Dry Tortugas	365	0	0	0	0	0
Everglades	8063	1.125	3.597	1.184	3.752	0.058
Gates of the Artic	104827	0.015	0.577	0.013	0.472	-0.002
Glacier Bay	24596	0	0	0	0	0
Glacier	7179	0.015	0.346	0.056	0.607	0.040
Grand Canyon	7181	0.077	0.970	0.065	0.717	-0.011
Grand Teton	2029	0.585	2.372	0.456	2.226	-0.129
Great Basin	464	0	0	0	0	0
Great Sand Dunes	222	0	0	0	0	0
Great Smoky Mountains	3020	0.890	3.143	1.070	3.423	0.179
Guadalupe Mountains	503	0	0	0	0	0
Haleakala	144	0	0	0	0	0

Name	Pixels	1992 Mean	1992 SD	2012 Mean	2012 SD	Change 1992 to 2012
Hawaii Volcanoes	1096	1.421	5.623	2.295	7.593	0.874
Hot Springs	35	46.314	13.819	51.657	12.357	5.342
Isle Royale	1013	0	0	0	0	0
Joshua Tree	4486	0.323	1.333	0.405	1.453	0.081
Katmai	36887	0	0	0	0	0
Kenai Fjords	6384	0.021	0.458	0.020	0.377	-0.001
Kings Canyon	2705	0	0	0.001	0.076	0.001
Kobuk Valley	21353	0	0	0	0	0
Lake Clark	38491	0	0	0	0	0
Lassen Volcanic	665	0	0	0	0	0
Mammoth Cave	299	1.846	2.857	1.765	3.209	-0.080
Mesa Verde	323	0.253	1.175	0.080	0.649	-0.173
Mount Rainier	1610	0.282	1.429	0.129	0.836	-0.153
North Cascades	3586	0	0	0.001	0.100	0.001
Olympic	6427	0.024	0.844	0.027	0.708	0.002
Petrified Forest	551	0	0	0.036	0.429	0.036
Redwood	731	0.543	1.704	0.295	1.285	-0.247
Rocky Mountain	1649	1.385	4.550	1.220	4.333	-0.164
Saguaro	534	4.917	3.986	3.988	4.523	-0.928
Sequoia	2379	0	0	0.018	0.293	0.018
Shenandoah	1212	0.626	2.437	0.886	2.633	0.260
Theodore Roosevelt	497	0.364	1.652	1.235	3.583	0.871
Voyageurs	1469	0.221	1.183	0.121	0.857	-0.100
Wind Cave	185	0	0	0	0	0
Wrangell - St Elias	129096	0	0	0.001	0.059	0.001
Yellowstone	14490	0.059	0.806	0.071	0.992	0.011
Yosemite	4467	0.033	0.557	0.043	0.472	0.010
Zion	881	0.335	1.376	0.390	1.687	0.054

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National Park Service
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