5.1 Light pollution

Author, affiliation: Michelle Greenwood (NIWA)

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State of knowledge of "Light Pollution" attribute: Good / established but incomplete

The International Commission on Illumination (CIE) defines light pollution as the "sum total of all adverse effects of artificial light". The impacts of light pollution on the visibility of the night sky are well understood and globally similar[1]. Ecological impacts of light pollution are generally consistent but will vary depending on the light sensitivity, behaviour and lifecycle of the focal organism, with potentially complex impacts across ecosystems due to species interactions[2-4]. While there is good international understanding of the ecological impacts of light pollution on a range of species and ecosystems, more limited New Zealand specific research has been undertaken, with none for marine mammals and herpetofauna[5]. Similarly, the recent and ongoing global conversion of outdoor lights to LEDs and associated shift in lighting spectra is a comparatively new research area[6, 7].

Section A—Attribute and method

A1. How does the attribute relate to ecological integrity ~~or human health~~?

There is strong evidence globally that light pollution negatively affects terrestrial[2, 8-10], freshwater[11-13], marine[14, 15] and agricultural ecosystems[16] by affecting species behaviour[17, 18], physiology, life-cycle timings, growth rates[13]**,** food availability [19] and interactions with other species[2]. Light pollution can be caused directly by illumination from light sources or indirectly through reflection off surfaces. Sky glow is an increase in apparent brightness of the night sky, exacerbated by reflection off clouds that extends far beyond urban areas[20]. Evidence is strong for multiple mechanisms of ecological impact including reduced visibility of the night sky impacting celestial navigation[21], behaviour and lifecycles regulated by the lunar cycle[14]. Other mechanisms include behavioural changes such as avoidance of lit areas[22], or increased predation opportunities[23, 24], leading to impacts on entire foodwebs [2]. There is more limited, but growing, research for specific impacts on New Zealand ecosystems[5].

The recent global switch to LEDs for outdoor lighting may result in stronger impacts of light pollution, due to common increases in blue light emissions[25]. Many insects are more sensitive to shorter wavelengths[26], and blue light scatters in the atmosphere more[27], penetrates deeper into water waterbodies[2] and may result in stronger impacts on human health [28]**.**

I focus on impacts on ecological integrity, however there is evidence for impacts of light pollution on cultural values (such as Māori astronomical knowledge (Tātai arorangi [29]) and human health[28]).

A2. What is the evidence of impact on (a) ecological integrity ~~or (b) human health~~? What is the spatial extent and magnitude of degradation?

The evidence is strong for impacts of light pollution on ecological integrity globally[10, 30-32]. While there are fewer studies specific to New Zealand[5, 8, 20, 33], the impacts are likely to be similar. Globally the spatial extent of impact is large, particularly for densely populated countries where there may be limited dark refuges[1, 34] and ~47% of the terrestrial land area globally affected by skyglow[35]. In contrast, New Zealand currently has very limited spatial extent of light pollution (~95% of land area with no light emissions)[5], although almost all (97%) of our population lives under skies impacted by light pollution[1]. However, skyglow from urban areas impacts night sky brightness and visibility at distance up to 100km, impacting marine areas[15] and ecological reserves in New Zealand [20, 27] and Key Biodiversity Areas internationally [36]. The spatial extent of light pollution is increasing in New Zealand, particularly around the edges of cities and in rural areas[5].

A3. What has been the pace and trajectory of change in this attribute, and what do we expect in the future 10 - 30 years under the status quo? Are impacts reversible or irreversible (within a generation)?

Globally the spatial extent of light pollution is increasing due to population expansion and the development of cheaper lighting sources[1, 37]. The average rate of increase in spatial area of light emissions in NZ was 4.2% between 2012 and 2021 [5], slightly above global average rate[1]. Although areas impacted by light pollution are increasing, the majority of the land area of New Zealand is still unimpacted by light emissions[5]. In addition, increasing numbers of semi-urban areas are being protected through the development of dark sky reserves and parks[38]. Improvements in lighting technology such as use of alternative light spectra, better shielding of lighting units and an ability to dim lights or use sensors or timers to reduce lighting duration, intensity and spatial extent are available. Light pollution is a relatively unique stressor with a straightforward solution to reducing impacts – turn the lights off (or down). We have the technology and enough knowledge of key mechanisms to reduce ecological impacts. It is theoretically relatively straightforward to reduce and reverse light pollution impacts using appropriate technology and policy.

A4-(i) What monitoring is currently done and how is it reported? (e.g., is there a standard, and how consistently is it used, who is monitoring for what purpose)? Is there a consensus on the most appropriate measurement method?

Light pollution is measured in a multitude of ways depending on whether the variable of interest is night sky visibility, ecological values, human health or human safety and inconsistencies between disciplines causes confusion [39]. There are recommendations for different methods and units of measurement depending on the goal of the monitoring[39]. Satellite imagery and astronaut photographs from the ISS are freely available to monitor upward light across broad spatial scales (https://eol.jsc.nasa.gov). StatsNZ reports estimates from satellite estimates from 2016 [1] as a national indicator of Artificial Sky Brightness (https://www.stats.govt.nz/indicators/artificial-night-skybrightness). Satellite imagery likely underestimates light pollution changes detected on the ground as not all lights are directed upwards[5, 37]. Citizen science projects exist for ground-based monitoring with free data[37]. In New Zealand there is no regular ground-based monitoring of light pollution, but small datasets exist from several methods (e.g., Sky Quality Meters, lux meters) which are commonly used methods internationally. These data are collected over limited spatial and temporal extents for research projects, community groups, dark sky areas and astronomical societies.

A4-(ii) Are there any implementation issues such as accessing privately owned land to collect repeat samples for regulatory informing purposes?

Monitoring implementation issues depend on the monitoring method. Satellite imagery is freely available but only monitors upwards light at a broad spatial scale and current satellites are not sensitive to blue light[39], which is problematic given the global conversion to predominantly blue-white LEDs for outdoor lighting. Setting up ground-based networks of continuously monitoring telemetered sensors could be relatively easy, depending on location requirements (e.g., private vs public land) and scale of the monitoring network. Night sky brightness and local light levels are influenced by cloud cover and would benefit from simultaneous monitoring of weather conditions. Remote predictions of cloud cover are available from NASA MERRA-2 climate analysis project but may not correlate well with local ground conditions.

A4-(iii) What are the costs associated with monitoring the attribute? This includes up-front costs to set up for monitoring (e.g., purchase of equipment) and on-going operational costs (e.g., analysis of samples).

Costs for monitoring depend on the data collection methods, which depends on the goal of the monitoring. Satellite imagery of upward light emissions is free with relatively minimal post-processing required. Ground-based Sky Quality Meters are comparatively cheap (~$250 each) although telemetered versions are more expensive. These could be installed on existing infrastructure with the cost dependent on the size of the monitoring network. Digital cameras can also be used or illuminance (lux) meters, which are not prohibitively expensive (approximately $100s to $5000). More expensive tools include more detailed imaging instruments. Most methods require relatively minimal post-processing, but calibration requirements vary. Conversion of collected data to indicator values or interactive live maps would involve a one-off cost to develop the code and set up the system but minimal ongoing costs.

A5. Are there examples of this being monitored by Iwi/Māori? If so, by who and how?

Night sky visibility has high cultural relevance given the importance, for example, of tātai arorangi (Māori astronomical knowledge), the maramataka (lunar calendar) in understanding seasons and time, cultural landscapes, celestial navigation and the ability to view the Matariki (Pleaides) constellation [29]. To reduce the impacts of light pollution on their cultural values and knowledge systems, several iwi/hapū/rūnanga are actively working towards dark sky sanctuary status (e.g., Te Rūnanga o Kaikoura [46]. Although we are not aware of any in-depth on-going monitoring of light pollution by iwi/hapū/rūnanga, monitoring of night sky visibility may be undertaken within some of the dark sky reserves (such as Aoraki Mackenzie International Dark Sky Reserve).

A6. Are there known correlations or relationships between this attribute and other attribute(s), and what are the nature of these relationships?

Light pollution is likely to impact and/or interact with many of the other listed attributes. However, methods to monitor light pollution are different from the other attributes and likely to be stand-alone.

Part B—Current state and allocation options

B1. What is the current state of the attribute?

We have a good understanding of the current state of upward light pollution at a broad national scale from satellite data[5]. StatsNZ reports estimates from satellite measurements from 2016 [1] as a time- static national indicator of Artificial Sky Brightness (https://www.stats.govt.nz/indicators/artificial-night-skybrightness). Currently a limited area of New Zealand is impacted by upward light pollution (<5%), although more will be impacted by sky glow[15, 27] and almost all our population lives under light polluted skies. An indicator could be developed at a national or regional scale using satellite data for upward light pollution. However, linking this to impacts on particular taxa or locations will be more challenging due to the scale mis-match, the fact that satellites don't monitor skyglow, limitations in the spectral sensitivity of the current satellites, and that light from non-upward directions also cause ecological impacts. Although satellite imagery can be a good indicator of local night sky brightness in some locations[15] we have comparatively poor understanding of light pollution at a local scale, at a broad-scale from directions that are not upward and the potential impacts on New Zealand taxa and ecosystems.

Development/choice of an indicator would need to consider what it was designed to monitor (night sky visibility or broad or specific ecological impacts) and the relevant spatial and temporal scale for monitoring would need to be decided before selecting an appropriate indicator. There are a selection of methods and approaches available with good review papers[39].

B2. Are there known natural reference states described for New Zealand that could inform management or allocation options?

Measurements from the large areas of New Zealand unimpacted by light pollution would provide good reference states for comparison to impacted areas. Light pollution could be monitored in remote areas, using selected/multiple units and measurement methods, to form baseline levels from areas with low/absent light pollution. The impact of cloud cover and lunar phase on lighting in these areas could be quantified and used to help understand these impacts in more lit/impacted areas.

B3. Are there any existing numeric or narrative bands described for this attribute? Are there any levels used in other jurisdictions that could inform bands? (e.g., US EPA, Biodiversity Convention, ANZECC, Regional Council set limit)

There are no national standards in New Zealand for light pollution. Appropriate levels will depend on the purpose light pollution is monitored for. Sky Quality Meters provide a scale for visibility of the night sky that ranges from dark skies with no light pollution to those found in major urban centres, and other scales exist based on the visibility of different constellations. Devising numeric bands for ecological impact would be more challenging as light and spectral sensitivity will vary between taxa.

B4. Are there any known thresholds or tipping points that relate to specific effects on ecological integrity ~~or human health~~?

There are thresholds for night sky visibility readings at which different components of the night sky are no longer visible (for example, the milky way). Thresholds for light pollution that have ecological impacts differ depending on the focal taxa or ecosystem and the units used to measure light pollution because species vary in their light and spectral sensitivity. Some general thresholds do co-occur for multiple taxa, however, such as brightness exceeding that present during a full moon, or brightness levels at which the lunar cycle is obscured.

B5. Are there lag times and legacy effects? What are the nature of these and how do they impact state and trend assessment? Furthermore, are there any naturally occurring processes, including long-term cycles, that may influence the state and trend assessments?

Light pollution will generally have limited lag or legacy effects. The immediate impact of light pollution can be removed by turning the lights off. Some lag effects may occur if community composition has shifted due to the impact of the lighting, with rates of community change after the light is removed depending on the activity of the species and proximity of sources of recolonists. The recent conversion of streetlights from older lighting technologies to LEDs may complicate assessment of historical trends of light pollution due to co-occurring shifts in lighting spectra and intensity at the time of the conversion and due to limitations in the spectral sensitivities of some of the monitoring methods. Lunar cycles and cloud cover also need to be accounted for in trend analyses.

B6. What tikanga Māori and mātauranga Māori could inform bands or allocation options? How? For example, by contributing to defining minimally disturbed conditions, or unacceptable degradation.

Star visibility is of cultural importance and use of existing bands that relate night sky brightness to the visibility of certain constellations could be appropriate.

Part C—Management levers and context

C1. What is the relationship between the state of the environment and stresses on that state? Can this relationship be quantified?

The relationship between management interventions and light pollution is comparatively easy to understand with use of models and spatial mapping to predict spectral and light intensity outputs occurring in the environment depending on different lighting periods, spectra, light shielding etc.

The relationship between night sky visibility and light pollution is also relatively well understood. The level of lighting reduction required to achieve night sky visibility of a certain level could likely be broadly predicted given local conditions, lunar cycles and atmospheric conditions.

The relationship between light pollution and ecological impacts is more complicated by different light and spectral sensitivities of different species. However, there is a strong consensus that in general, less light is better, and that often a spectral change to reduce the short wavelength light (such as blue light) reduces impacts.

C2. Are there interventions/mechanisms being used to affect this attribute? What evidence is there to show that they are/are not being implemented and being effective?

Compared to other types of environmental stressors light pollution may be a relatively easy problem to solve[40]. Preventing new areas being lit or using straightforward approaches to reduce light spill, intensity, durations and the use of short-wave length lighting are obvious solutions[2]. A lack of regulations, funding and guidelines are likely limiting implementation of these solutions. A list of management interventions by level of organisation is below:

C2-(i). Local government driven

Almost all district plans contain rules to limit the effects of light spill and glare onto adjacent properties, but few currently include objectives to control the type and quantity of lighting that can be installed to limit ecological impacts. The development of dark sky places encourages such changes. Southland District council has included a plan change for lighting rules on Rakiura-Stewart Island since the development of the Dark Sky sanctuary and the Timaru District Council plan has rules pertaining to the Aoraki Mackenzie International Dark Sky Reserve and recognises the benefits of protecting the night sky.

C2-(ii). Central government driven

There are no central government rules associated with light pollution that I am aware of. New Zealand Transport Agency Waka Kotahi have standards for lighting safety but there are no national policy or standards to reduce the ecological impacts of light pollution.

C2-(iii). Iwi/hapū driven

Iwi/hapū/rūnanga are a driving force behind the development of dark sky areas and have strong public influence and education roles. An example is the Aoraki Mackenzie International Dark Sky Reserve, Dark Sky Project in Tekapo/Takapō, a Ngāi Tahu project, which promotes education around the importance of dark sky preservation.

C2-(iv). NGO, community driven

Community groups and NGO such as dark sky groups and astronomy organisations also contribute strongly to the development of dark sky areas to improve night sky visibility. To be a dark sky area there are lighting requirements that are required to be met before the area can be internationally accredited by the International Dark Sky Association (IDA). The IDA is a non-government not-for-profit organisation established to "preserve and protect the night-time environment and our heritage of dark skies through environmentally responsible outdoor lighting". These include restrictions on the amount of blue light emitted by lighting sources.

Voluntary best-practice guidelines have been developed for several sectors, for example to reduce seabird attraction to commercial fishing vessels[41]. Recognition of the ecological impacts of lighting is supported by the lighting industry in general[42].

C2-(v). Internationally driven

Internationally the importance of darkness within networks of interconnected lit habitats is being recognised but rules to limit lighting are country-specific. Countries with nationwide legislation to reduce the impacts of light pollution include Croatia, France, and Slovenia[43]. Accreditation by the IDA as a dark sky place is strongly attractive and is dependent on meeting lighting criteria. New

Zealand is part of the United Nation's convention on conservation of migratory species, which have endorsed ecological light pollution guidelines.

Part D—Impact analysis

D1. What would be the environmental/~~human health~~ impacts of not managing this attribute?

The ecological implications of light pollution can be major[2]. More than 50% of New Zealanders cannot see the Milky Way from home [1]. Although the spatial area of New Zealand impacted by direct illumination is very low, these areas can contain important ecological reserves or key populations of taonga species[20]. Larger spatial areas are also impacted by skyglow. Not managing this attribute, particularly as population growth increases the lit area will contribute to species loss and ecological function. There will also be a loss of potential financial gains from astro-tourism, increases in energy costs to light larger areas, and significant cultural impacts. For example, the night sky is integral to tikanga and mātauranga Māori, as evidenced through Māori astronomical knowledge (Tātai arorangi [29]), including Matariki. By not managing this attribute, the importance of the lunar calendar (maramataka) in understanding seasonal processes and the passing of time, and in use of celestial navigation will be impacted.

D2. Where and on who would the economic impacts likely be felt? (e.g., Horticulture in Hawke's Bay, Electricity generation, Housing availability and supply in Auckland)

An improvement in light pollution in New Zealand has potential for strong economic benefits as noted in [38]. Using less light will lead to costs savings associated with a reduction in energy use[38]. Astro-tourism can have significant financial benefits and is blooming globally [44]. For example, before the covid pandemic (2020) the Aoraki Mackenzie International Dark Sky Reserve (AMIDSR) had 9 astro-tourism companies operating with visitors to the region spending almost a million dollars a day[38]. New Zealand is world leader in dark sky locations, with the southern-most (Rakiura /Stewart Island) and the largest in the southern hemisphere (AMIDSR). In early 2023 New Zealand had five dark sky places with approximately 15 more hoping to receive such accreditation[38]. An ambitious plan aspires to make New Zealand the second dark sky nation (after Niue): What's a 'dark sky nation' and why does New Zealand want to become one? (nationalgeographic.com)

Costs associated with light pollution causing potential reduction in agricultural productivity[16] or unexpected ecological outcomes in combination with other stressors are likely[45], but difficult to predict or quantify.

D3. How will this attribute be affected by climate change? What will that require in terms of management response to mitigate this?

Environmental changes associated with climate change will not have direct effects on the intensity or spatial distribution of light pollution. Indirect effects may occur through changes in the spatial distribution of urban centres as flood-risk, precipitation or temperature changes alters the habitability of areas. However, the impacts of light pollution will likely have synergistic and potentially unexpected impacts for many taxa and ecosystems in combination with environmental changes caused by climate change[45].

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