Effects of Artificial Light on Urban Wildlife within the Lower Hutt District

Photobiology Assessment

NZ0120185

Prepared for
Hutt City Council

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Cardno®

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Executive Summary

Hutt City Council requested that Cardno (NZ) review potential effects of artificial night-light on native urban wildlife including birds, mammals, lizards, insects and freshwater fish within the Lower Hutt District.

Population growth and urbanisation of Lower Hutt District has gradually increased and is predicted to carry on increasing. This will likely result in the increased use of outdoor lighting at night. Lower Hutt District is one of the most light polluted areas of the lower North Island. The current levels of artificial light, especially in the more densely populated areas of the city, are such that it is no longer possible to see the Milky Way at night, and light pollution also extends to the more remote areas of the District.

More than 1,000 native species are known to inhabit the Lower Hutt District and many of these species are active at night (nocturnal) and/or move through the landscape at night including longer distance migration species. Thus, there are a range of species that are susceptible to the effects of light pollution.

There are a wide range of potential effects of artificial lighting on fauna which includes behaviour changes, physiological changes, changes to how and when species interact with their environment, reproductive and growth changes. Research on the effects of light on fauna is increasing, but is still relatively limited. Little information could be located for many of the New Zealand fauna, or their overseas relatives.

The effects of light also vary according to the type of light used (five main types of light are briefly described) and the effects of different light types are different for different taxonomic groups. Vertebrate species may be less attracted to lights in the blue spectrum (although this is by no-means certain for New Zealand species) while invertebrates may be less attracted to lights in the orange spectrum (variable between species).

There are some international policies on the management of light pollution, but no national standards in New Zealand. Parts of the country (the MacKenzie Basin and the Wairarapa) are striving to maintain or improve the darkness of the night, and some district plans include policies to manage the effects of outdoor lighting – including on fauna and natural areas.

The reported scale of increased light effects can extend over 200 km and can include ecosystem scale effects including changes to primary production and plant growth, changes in species distribution and movement through the landscape with resultant changes in populations, changes to interactions and abundance of species within a food web, and temporary or long-term consequences for biodiversity.

Management of effects could include the adoption of lighting objectives and best practice principles, gradual replacement of lighting infrastructure with less light-polluting option, encouraging landowners to switch off lights at night, careful selection of the colour of the light to reduce effects on local fauna, provisions in the District Plan for dark sky areas, and placement and type of lighting close to natural features.

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1 Introduction

Hutt City Council requested that Cardno (NZ) undertake a literature review of potential adverse effects of artificial outdoor light on native wildlife within the Lower Hutt District[1]. This study looks at the types of artificial light sources, their impact on the photo-physical structure of the natural environment and photobiology effects on urban wildlife fauna overseas and in New Zealand.

1.1 Scope of the study

The scope of this study is as follows:

> Summarise available literature, including the research findings on the nature and magnitude of the effects of artificial outdoor light on urban wildlife species (birds, lizards, invertebrates, fish, and mammals) but will exclude effects on plants, humans, or marine animals except to the extent marine animals are affected by light sources on land;

> Summarise any major gaps in knowledge of the photobiological effects on species, and whether filling those gaps could be accomplished by further desktop analysis or field research;

> Provide an expert opinion on the degree to which the current understanding of photobiology effects on specified urban wildlife taxa is relevant to the Lower Hutt District; and

> Provide relevant broad recommendations on how artificial outdoor lighting should be designed, or the use of lighting limited, to reduce known significant negative impacts of light on native wildlife.

2 Methods

This study was a desktop assessment based on a comprehensive literature review. Data on which species occur within the Lower Hutt District was compiled from databases to help focus which species (or related overseas species) should be investigated. The study also looked at the literature on management of wildlife affected by artificial night-light.

Records of fauna including birds, mammals, lizards, insects and freshwater fish were collated from online geodatabases. The NZ iNaturalist community database provided 122,234 observational records of birds, mammals, lizards, insects and fish within the study area since 2000 (Figure 2-1).

Freshwater fish records were collated from the New Zealand Freshwater Fish Database (NZFFD). There were 318 records for fish (and some large invertebrate species) within the Lower Hutt District since 1990 (Crow 2017).

The list of species that occur in the Lower Hutt District was compiled for the following species groups: birds, mammals, lizards and freshwater fish. Insect data was compiled at the level of insect orders.

Biological traits such as the diurnal/nocturnal behaviour, migration, and conservation status of the species or orders were determined from relevant literature. These data are provided in Appendix A and summarised in Table 3-1.

The literature review of photobiology effects focussed on three aspects:

(i) the types of artificial outdoor lighting;

(ii) potential effects of light pollution on urban wildlife and ecosystems; and

(iii) current policy and resource management approaches to light pollution.

1 For clarity, the predominantly urban area of the district along the Hutt River is referred to as Hutt City, and the entire district is referred to as Lower Hutt District.

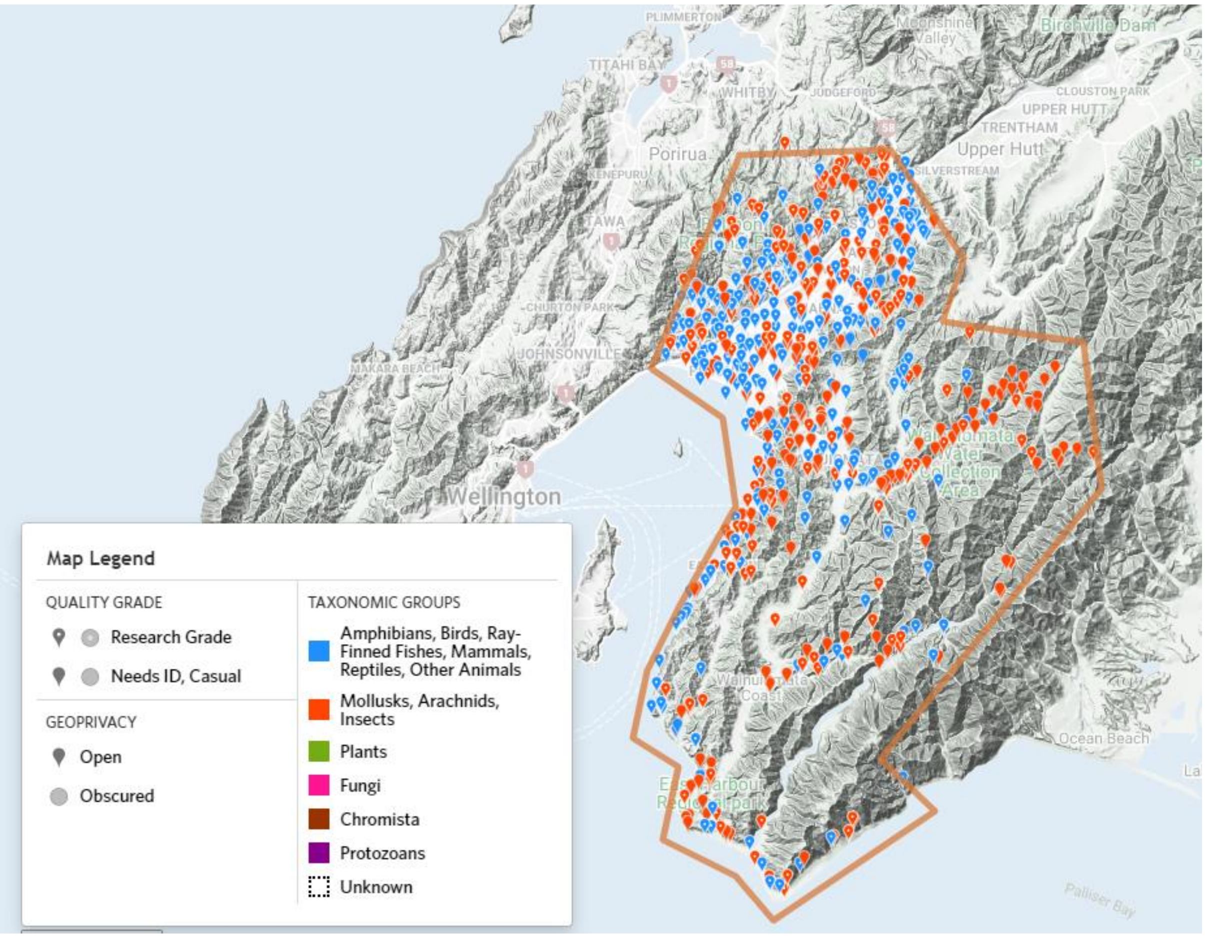

Figure 2-1 Locations of NZ iNaturalist fauna observations since 2000.
Only the data for vertebrates (blue symbols) and invertebrates (red symbols) were collated.

3 Background

With the continuing growth of the human population, urban expansion areas is a common trend across the globe (Seto *et al*., 2012). In 2019 it was estimated that 86.62% of New Zealand's total population lived in urban areas and cities (Plecher, 2020) and this is projected to increase to over 90% by 2050 (The United Nations Department of Economic and Social Affairs (UN-DESA), 2018) (Figure 3-1).

This expansion of urban areas is accompanied by the development of housing, industrial and transport infrastructure. Increased urbanisation generally results in dramatic changes in the quality of natural environment, including an increase of artificial light sources such as electric lamps and electronic devices.

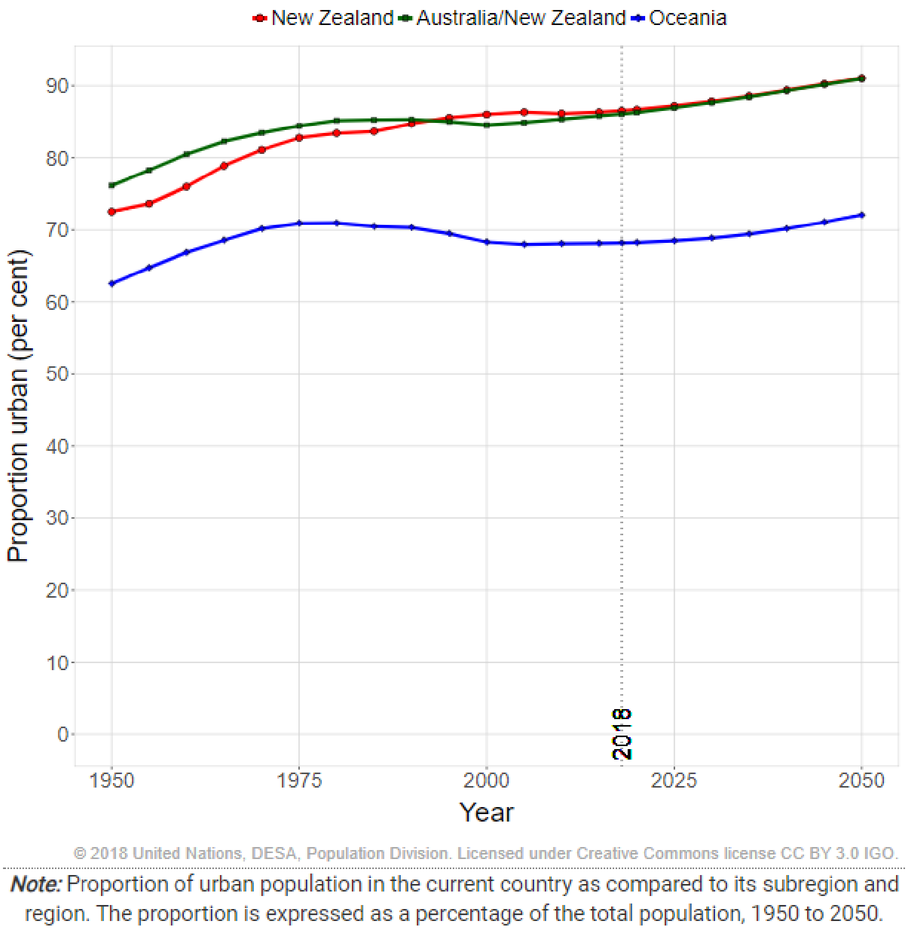

Figure 3-1 Estimates and projections of urban populations in New Zealand, Australia and Oceania from 1950 to 2050 (Source: UN-DESA, 2018)

3.2 Study area

Lower Hutt District is New Zealand's sixth most populous area, with a population of 111,800. The district comprises 377 km^2 of which over a third (135 km^2) is urban[2]. Hutt City is located along the eastern shores of Wellington Harbour in the lower half of the Hutt Valley, and is densely urbanised. The Wainuiomata valley is more rural and dominated by farmland and forested areas, with an urban component.

Figure 3-2 illustrates the population estimates and projections for Lower Hutt District from 2003 to 2043. The most likely scenario is that the population will continue to increase.

[2] http://www.huttcity.govt.nz/

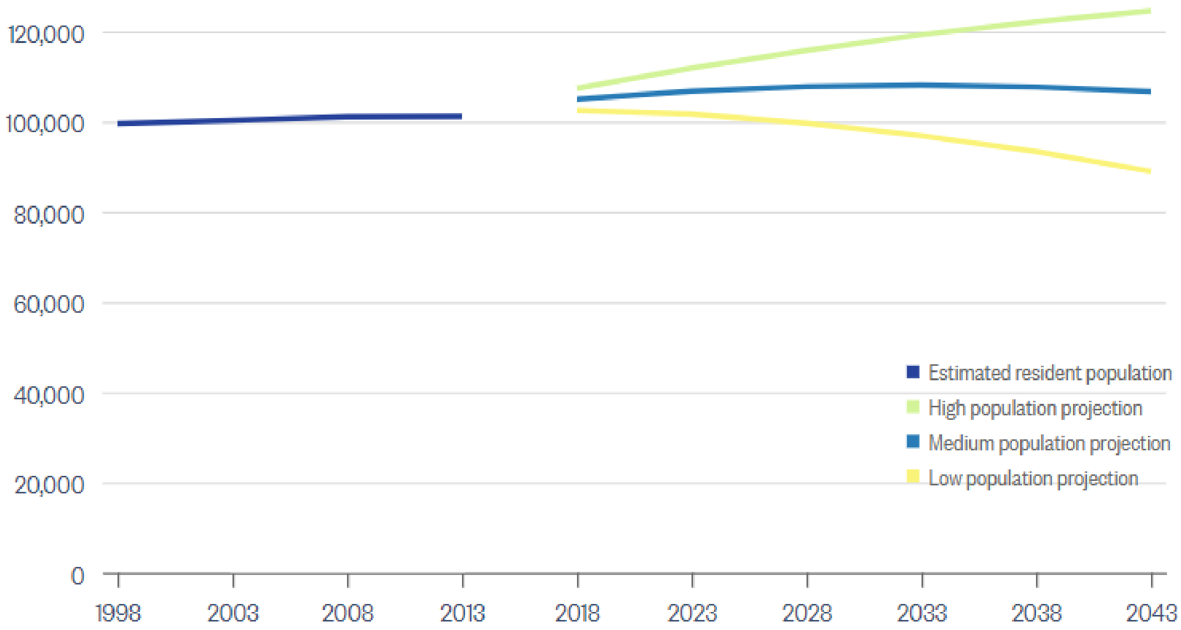

Figure 3-2 Population estimates and projections for Lower Hutt District from 2003 to 2043 (Source: Stats NZ, 2020)

3.3 Fauna in Lower Hutt District

More than 1,000 native fauna species have been recorded from the Lower Hutt District, the bulk of which comprise invertebrate species (937). More than 4% of the non-invertebrate species are categorised as being Threatened or At Risk in the New Zealand Threat Classification System (Hitchmough 2013). Including the invertebrate species would likely have resulted in a higher number of threatened species but it was outside the scope of this report to compile threat rankings for the multitude of invertebrates present across the district[3] (Table 3-1).

Many species of fauna are most active during the day (diurnal), but others are active during the day and at night (nocturnal), especially species that move long distances. There are some species that are mainly active at night, and that includes morepork, kiwi, bats, native fish, and some invertebrate taxa. Species that are active at night will be most susceptible to the effects of artificial light pollution. The number of species within each taxonomic group that are known to be active at night are summarised in Table 3-1 and more detail is provided in Appendix A.

Species that move long distances, or move regularly throughout the landscape, are potentially at greater risk of encountering areas with increased light at night.

There are different types of fauna movement. They have been categorised as follows:

> Not migratory – no seasonal or hormone induced movement of individuals or flocks/groups.

> Long-range dispersal – juveniles moving long distances from natal territories.

> Seasonal migration – individuals moving around the landscape to take advantage of different or seasonal food sources (e.g. different fruiting species, or moving to warmer altitudes to forage on insects, or moving to a particular breeding area).

> Nomadic – flocks or groups of animals moving en masse to find more favourable habitat (e.g. the pond has dried up so move to a different waterbody).

[3] Insect data was compiled at the level of insect orders.

> Migration – hormone induced movement of individuals or flocks/groups of fauna; can be within NZ and/or international.

Table 3-1 summarises the number of species per taxonomic group that undertake regular movement throughout the landscape; that is seasonal migration, nomadic movements, or migration. Lizards are not thought to migrate over long distances, but there is insufficient data to be certain.

Table 3-1 Number of native species recorded within the Lower Hutt District, their threat status, known nocturnal activity and migratory behaviour

Taxonomic group	Number of native species recorded	Number of species Classified as Threatened or At-Risk[4]	Number of species with known nocturnal behaviour	Number of known migratory species
Birds	58	24	25	44
Mammals (terrestrial)	1	1	1	1
Mammals (marine)	2	1	2	1
Lizards	12	9	5	DD
Invertebrates	937	NA	NA	NA
Fish (freshwater)	17	9	17	12
Total	**1,027**	**44**	**50**	**69**

DD = Data Deficient, NA = Not Assessed, excluded from the assessment due to data deficiency (such as not having species level identification) and/or limited behavioural records available.

3.4 Forms of artificial light

The planet Earth receives electromagnetic radiation from both extrinsic and intrinsic sources. The external natural electromagnetic radiation sources are the sun, stars, our moon and planets that reflect cosmic light. Intrinsic natural sources of electromagnetic radiation include lightning, volcanic eruptions, bushfire and light emitting organisms (e.g. fireflies, jellyfish, glow-worm, bio-luminescent fungi and plankton). In addition to these natural light sources, a vast amount of electromagnetic radiation is released from anthropogenic sources to the Earth’s atmosphere, including from human-made light sources which are referred to as artificial light (NASA Science 2020).

The visible light spectrum is the range of wavelengths of the electromagnetic spectrum that the human eye can see. Isaac Newton's experiment in 1665 showed that a prism bends visible (white) light and that each colour refracts at a slightly different angle depending on the wavelength of the colour. Each colour in a rainbow corresponds to a different wavelength of the electromagnetic spectrum. Some animals can see in parts of the spectrum that humans cannot. Typically, the human eye can detect wavelengths from 380 to 700 nanometres (NASA Science 2020) as illustrated in Figure 3-3.

Artificial light sources are immensely useful in our day-today and night-time activities. Artificial white light is a range of colours, and may include colours not visible to humans. Coloured light is generated from a narrower range of wavelengths.

Advanced broad-spectrum lighting is used in many technical applications, including household lighting, computer and phone screens, televisions, security, architectural, cultural, outdoor feature tree illumination, and street lighting. The broad-spectrum white light sources differ in their colour appearance, ranging from warmer red-yellowish light to cooler/brighter blueish light.

4 New Zealand Threat Classification as per Hitchmough (2013).

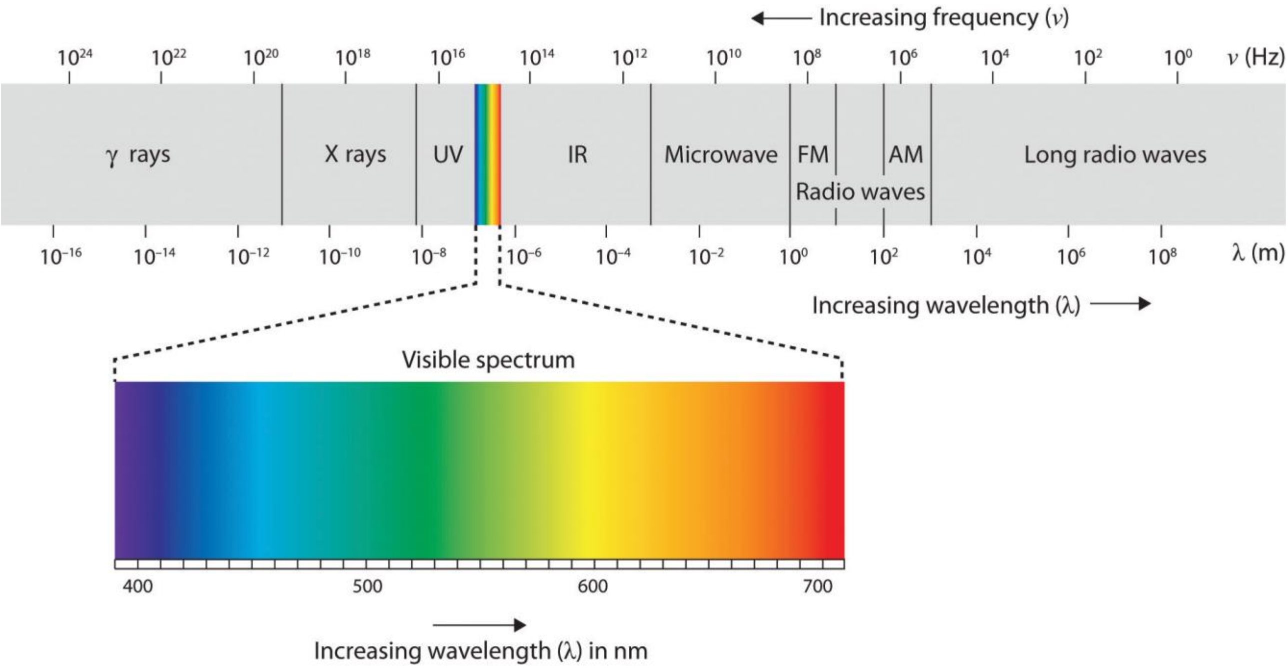

Figure 3-3 Humans can only see a very small part of the electromagnetic spectrum
(Source: NASA Science 2020)

Table 3-2 and Figure 3-4 illustrate the correlated colour temperature (CCT), measured in Kelvin (Department of the Environment and Energy, 2020; Royal Society NZ, 2018), which is a gauge of how yellow or blue the colour of light emitted from a light bulb appears.

Table 3-2 Blue light emitted by selected outdoor lighting sources at equivalent lumen output (luminous flux 1000 lm)
(Source: Royal Society NZ, 2018)

Light source	CCT (K)	% Blue colour
Narrowband Amber LED	1606	0%
Low-Pressure Sodium	1718	0%
PC Amber LED	1872	1%
High-Pressure Sodium	2041	10%
PC White LED (2700 K)	2700	15% - 21%
PC White LED(3000 K)	3000	18% - 25%
PC White LED(4000 K)	4000	26% - 33%
Metal Halide	4002	33%
Mercury Vapour	6924	36%
PC White LED (5000 K)	5000	35% - 40%

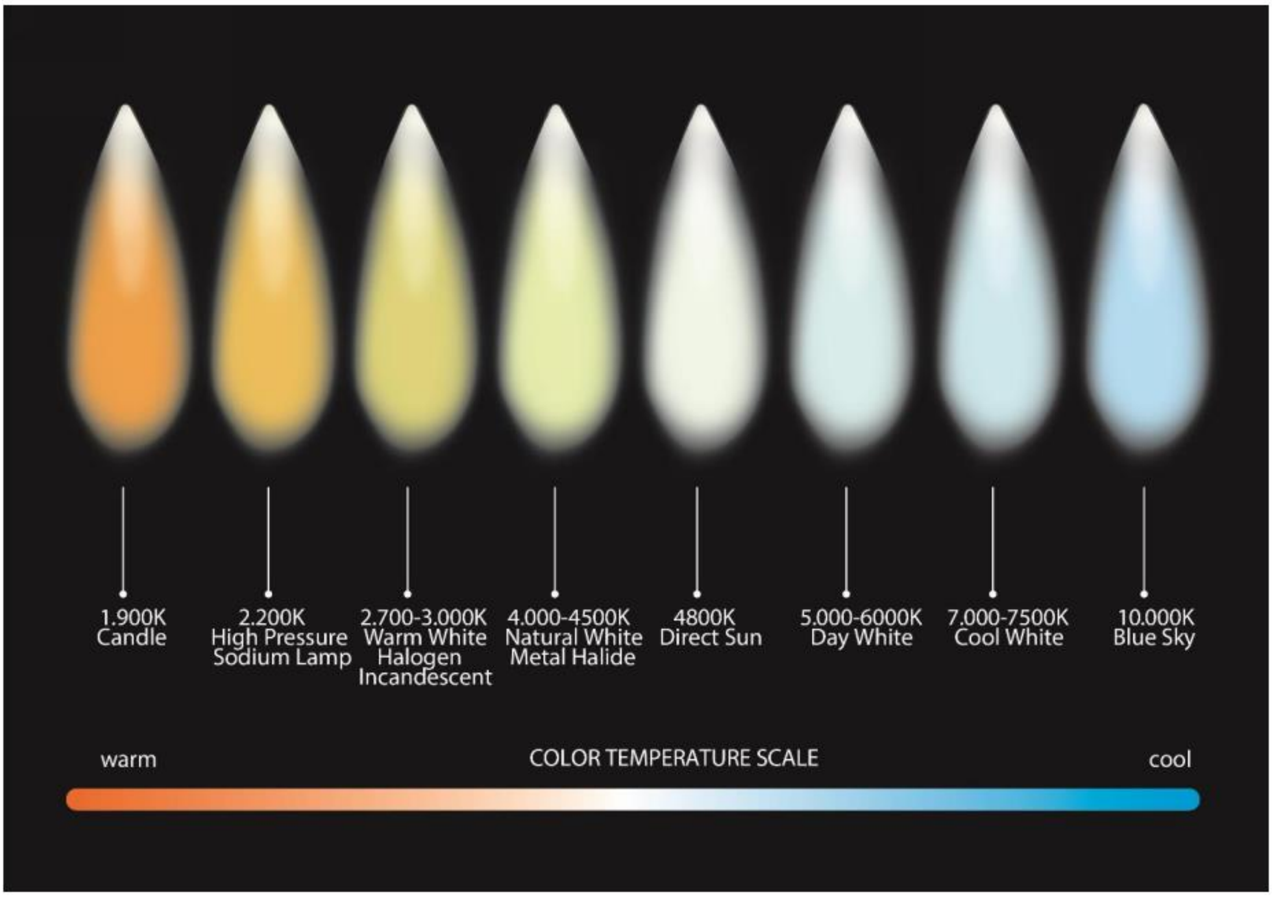

Figure 3-4 Correlated Colour Temperature (CCT) of some natural and artificial light sources from warm (1,000K) to cool (10,000K) (Source: Department of the Environment and Energy, 2020)

There is some evidence that increased exposure to blue-light from artificial sources has adverse impacts on humans, such as disruption to circadian rhythm (day/night cycle) and eye damage. Blue light may also have some benefits including better visibility compared to other sources of artificial light and effective treatment of behavioural disorders (Royal Society NZ, 2018).

Artificially produced light falls into five broad categories:

> Incandescent light
> Tungsten-Halogen light
> Fluorescent light
> Light-Emitting Diodes (LED)
> High-Intensity Discharge (HID) light

These are explained in more detail below.

3.4.2 Incandescent light

When certain objects (e.g. metals) are heated to a high temperature, they begin to emit light. Both infrared and visible light is produced in this process known as incandescence. Candles and incandescent bulbs are examples of incandescent sources of artificial light.

Incandescent light bulbs emit both heat and light. The colour spectrum of incandescent lighting is closer to natural light than other light sources, thus it was traditionally the preferred source for general-purpose illumination.

However, incandescent bulbs are energy inefficient and are being replaced in many applications by devices such as fluorescent lamps, HIDs (High-Intensity Discharges) and LEDs (Light Emitting Diodes), which produce more visible light for the same amount of electrical energy input.

3.4.3 Tungsten-Halogen light

Tungsten-halogen lighting (commonly referred to as halogen lights) is a type of incandescent lighting where a bulb's filament is surrounded by an inert gas and a small amount of halogen, which makes the bulb more efficient and increases its lifespan.

Halogen lighting produces a bright white light and provides more light per unit of electricity than regular incandescent bulbs, making it a good source of task-lighting. Because halogen lights are so bright, the positioning of light bulbs needs to be considered to reduce glare and shadow.

Halogen lights also give off a great amount of heat, which is an important safety consideration in any built environment. There is a higher risk of burn injuries from halogen lights, particularly for people with poor vision.

3.4.4 Fluorescent light

Fluorescent lighting consumes less electricity, lasts longer, and does not radiate as much heat as incandescent lights. Originally, florescent lights were produced in the form of tubes that create a line of light. This was the traditional lighting environment in large buildings and offices. A fluorescent tube is a more diffuse and physically larger light source than an incandescent bulb. In suitably designed lamps, fluorescent light can be more evenly distributed without a point source of glare as produced by an incandescent filament.

Subsequently, the technological advancements have resulted in Compact Fluorescent Lamps (CFLs) which are more light-bulb shaped. CFLs provide good overall light and are increasingly popular in the built environment. Many jurisdictions encourage their use as an energy-saving measure through incentive programs and legislation.

The disadvantage of fluorescent lighting is the slight flicker it produces. This flicker-effect can be counteracted by using proper lenses to shield the light source to provide even, indirect lighting, or using two tubes operating in phase opposition. These fixtures produce a substantially reduced flicker when used as an indirect light source or combined with prismatic diffusion covers, lattices, translucent shades or cover panels.

Fluorescent lighting now comes in a range of shades in the light spectrum. The cool "blue" tones of the past poorly represented natural or incandescent light. Today's better formulations of phosphor inside the tubes provide warmer tones. The best "soft" or "warm" white fluorescent bulbs now available are similar in colour to standard incandescent lighting.

Dimmable fluorescent lighting fixtures, which use electronic ballasts working at a high frequency, reduce both the flicker of light and energy consumption. Reduced flickering is less tiring and distracting for older adults and people with vision loss, particularly those who rely on peripheral vision.

3.4.5 Light-Emitting Diodes (LED)

LEDs emit an energy-efficient light when electricity is applied to a simple circuit. Modern LED bulbs produce light that is very similar to daylight (historically only red LEDs were available). LEDs were traditionally used as indicator lights on electronic devices. LED bulbs are now used in wider applications including signage, streetlamps and architectural detail lighting.

They are frequently used as a directional light source, or to focus light on an object or building element such as a sign or reception desk. LED lighting is also used for task-lighting or spotlighting (e.g. under kitchen cabinets to illuminate countertops). LEDs can also be configured in arrays within bulbs, providing multi-directional illumination similar to that produced by incandescent bulbs. LED bulbs produce no ultraviolet (UV) radiation and little heat, making them ideal for illuminating objects that are sensitive to UV light, such as works of art.

The LED lights are becoming more popular because they have high energy efficiency, operational convenience (e.g. they light up instantly, can be easily dimmed, operate silently), long lasting and relatively cheap to produce.

3.4.6 High-Intensity Discharge (HID) light

HID bulbs are a type of arc lamp that have a longer life and provide more light (lumens) per watt than any other light source. They are available in mercury vapour, metal halide, and high- and low-pressure sodium types.

Low-pressure sodium vapour lamps are extremely efficient. They produce a deep yellow-orange light and have an effective colour rendering index of nearly zero[5]. Items viewed under their light appear monochromatic[6], which has implications for people with vision loss.

Metal halide and ceramic metal halide bulbs can be made to give off neutral white light, which is useful for applications where normal colour appearance is critical (e.g., TV and movie production, indoor or night-time sports games, automotive headlamps and aquarium lighting).

High-pressure sodium lamps tend to produce a much whiter light, but still with a characteristic orange-pink cast. New colour-corrected versions producing a whiter light are available, but some efficiency is sacrificed for the improved colour.

HID lamps are typically used in large areas that require high levels of overhead light and when energy efficiency and/or light intensity are desired, such as gymnasiums, large public areas, warehouses, movie theatres, football stadiums, outdoor activity areas, roadways, parking lots and pathways. More recently, HID lamps, especially metal halide, have been used in small retail and residential environments. HID lamps have made indoor gardening practical, particularly for plants that require a good deal of high-intensity sunlight.

Brand new high-intensity discharge lamps make more visible light per unit of electric power consumed than fluorescent and incandescent lamps, since a greater proportion of their radiation is visible light in contrast to infrared. However, the lumen output of HID lighting can deteriorate by up to 70% over 10,000 burning hours.

3.5 Types of photobiology effects

Photobiology is the scientific study of the beneficial and harmful interactions of light (technically, non-ionizing radiation) in living organisms. The field covers a wide range of disciplines from photophysics to bioluminescence. However, this report focusses on the effects of photobiology relevant to New Zealand native fauna.

Non-ionising radiation generates excited states in molecules by absorbing the photons (light ‘particles’). These excited molecules react with neighbouring molecules and change their chemical and physical structure as a result of the absorption of light.

Figure 3-5 illustrates the three major groups of non-ionising radiation which can result in different photobiological effects:

> Ultraviolet (UV) radiation - short wavelengths that are outside the perception range of humans and can cause cellular changes;

> Visible radiation - longer wavelengths between 380 and 700 nm can result in changes in behaviour and species distribution; and

> Infrared (IR) radiation - long wavelengths that are outside the perception range of humans and generally perceived as heat.

[5] Colour rendering index (CRI) is an index, from 0 to 100, that measures the ability of a light source to reveal colours of objects, compared to a natural light source such as the sun filtering in through your windows. Simply put, it's the measurement of light in relation to how it affects the appearance of colour. A light source with a high CRI will produce a more accurate colour rendering of the objects around it.

[6] Containing or using only one colour.

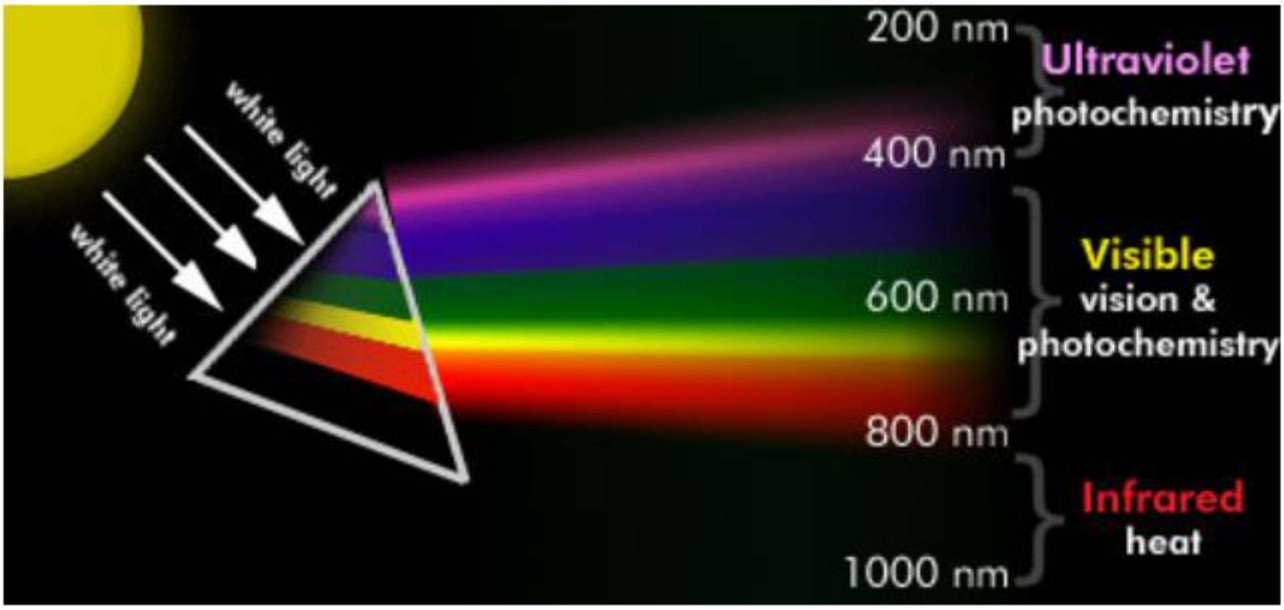

Figure 3-5 Dispersal of sunlight into a spectrum, indicating the types of photobiology effects such as photochemical, visual and heat effects related to the respective regions of the spectrum.

3.5.1 UV radiation effects

UV radiation can change the chemical and physical structure of important organic molecules, including deoxyribonucleic acid (DNA), ribonucleic acid (RNA) and proteins. Changes in DNA can lead to gene mutations, while changes in RNA result in altered proteins and are likely to affect the physiology of organisms including their growth and may even be lethal.

3.5.2 Visible light effects

Movement and distribution

Increased levels of light can affect how fauna use and move through a landscape. A nocturnal species may find an artificially lit area too bright and will avoid the area. This can result in migration failure such as fish not moving upstream of a highly lit area. It may also change species distribution in an area. For example, if prey species avoid a brightly lit area this may force predators to move away as well as there is insufficient food. Increased light may attract species to areas of greater danger. For instance, moths can congregate beneath street-lights putting bats at greater risk of collision with vehicles as they hunt out their prey. The impact on a single species or taxa may potentially have ecosystem-scale impacts, including alterations in the food web and ecosystem functions such as nutrient cycling.

Resetting the clock

Artificial light at night can supress the production of melatonin—the “hormone of darkness” in vertebrates. This hormone is a key player in circadian clock regulation which is a natural, internal process that regulates the sleep-wake cycle and repeats/resets on each rotation of the Earth roughly every 24 hours. These 24-hour rhythms have been widely observed in plants, animals, fungi, and cyanobacteria. Melatonin is suppressed in many vertebrates by extremely low light intensities, ranging from 0.01–0.03 lux for fishes and rodents to 6 lux for sensitive humans. For some wavelengths (colour of light), even lower light intensities are implied by some studies and there are major research gaps about the lowest light level that will trigger melatonin suppression for most species groups, and a lack of rigorous testing in ecological settings (Grubisic *et al*., 2020).

Photoperiodism, is the functional or behavioural response of an organism to changes of duration in daily, seasonal, or yearly cycles of light and darkness. This includes (amongst other things):

- flowers and leaves opening when it is light (or over a certain light threshold) and closing when it gets dark;
- Animals moving to or from nests or roosts;

- Bird dawn chorus;
- Daylength triggering bud dormancy or bulb or tuber growth;
- Triggering movement and breeding patterns such as migration, egg laying or spawning;
- Triggering development of different social life stages such as worker bees or soldier aphids; and
- Daylength growth response – for instance rodents born in the spring will grow to adult size, undergo puberty, and become reproductive in 6–8 weeks, whereas a sibling born in the autumn will not grow or undergo puberty for 4–5 months.

Photoperiodic reactions can be reasonably well predicted in natural situations, but temperature, nutrition, and other environmental factors such as increased artificial light also modify an organism's response.

Visual effects

Too much light, or light of the wrong colour can interfere with how an organism perceives their surroundings. For instance, monochromatic light could obscure visual cues on flowers directing pollinators to the pollen; increased light can increase hunting efficiency of predators that rely on sight; and insects may be attracted by artificial lights to areas that are not suitable for egg-laying.

Light influenced development

Photomorphogenesis is light influenced development of plants (rare in animals) triggered by the quantity, the quality (i.e., wavelengths present), the spatial asymmetry (i.e., the direction from which the light comes), and the periodicity of the light. Some examples of photomorphogenesis are the germination of light sensitive seeds (i.e. will not germinate if buried), and the flowering of long-day plants (the difference between spring and summer flowering plants). If these plant related processes are changed this can affect the animals that rely on them, such as lack of fresh growth, reduced nectar and pollen production, or fewer hiding places due to reduced vegetation cover.

Photomovement

Plants, animals, and organisms (e.g. fungi, bacteria) are influenced by the quality and the direction of the light striking their photoreceptors. When an organism moves toward or away from light this is known as photokinesis.

Phototropic curvature in plants can occur toward or away from the light. The best known example of this is sunflowers. Changes, and especially increases in light, can cause behavioural changes in how a species uses a space.

Photosynthesis

All animals rely on plants, whether it is the herbivore species that eat plants, the carnivore species that eat the herbivores, or as accommodation. Photosynthesis is what plants do to convert light energy to stabilised chemical energy. Without this light harvesting reaction there would be little life on Earth (there are some exceptions where species harvest energy from other sources). Increased artificial light of the correct wavelengths is used to promote plant growth. However, artificial light at night can disrupt seasonal light cues which can have far-reaching effects, including (Bennie *et al*., 2016):

> Mismatches in timing with herbivore grazing and migration patterns;
> Altering the development of agricultural crops or fauna food sources;
> Inhibiting flowering of some plant species;
> Decreasing periods of darkness necessary for plant repair from environmental pollutants; and
> Causing barriers to nocturnal pollinator species.

Bioluminescence

Well known examples of bioluminescence include the flash of a firefly, the glow of the glow-worm, and the phosphorescence that can occur when agitating the surface of the ocean. Bioluminescence is the highly efficient cold-light emission that fulfils an important biological function for the organism concerned (e.g. finding a mate or food). Bioluminescence occurs in many organisms, including plants, animals and fungi. Increased artificial lighting will reduce the relative light intensity of the bioluminescent output i.e. it is much harder to see a small pin-prick of light against a light background compared to a dark background.

3.5.3 Infrared effects

Infrared light is mostly associated with heat production. Increased of artificial light has contributed to urban areas being hotter than adjacent unlit areas. This can result in behavioural changes throughout the seasons. This effect can be especially pronounced during cooler months, for instance, a failure to hibernate or become dormant. Organisms that come in contact with hot lights can also sustain burns to the skin, and smaller creatures (e.g. insects) can completely burn up.

3.6 International light pollution management

Since the 1950s, there have been several policy and regulatory initiatives to minimise the adverse effects of artificial lights on humans, wildlife and ecosystems, at global, national and regional scales. In 2017, the 'Declaration in Defence of the Night Sky and the Right to Starlight' was formulated by a group of global organisations, including the United Nations Educational, Scientific and Cultural Organisation (UNESCO) and the Convention on the Conservation of Migratory Species of Wild Animals. The basis of this policy is to protect the pristine night sky to benefit human well-being, society, culture, biodiversity and environment (Zielinska-Dabkowska, 2020). The policy states that:

> "*an unpolluted night sky that allows the enjoyment and contemplation of the firmament should be considered an inalienable right of human kind equivalent to all other environmental, social and cultural rights, due to its impact on the development of all peoples and on the conservation of biodiversity*."

Figure 3-6 The five principles for responsible outdoor lighting
(Source: International Dark-Sky Association, 2020)

There are a range of organisations across the globe with initiatives or campaigning on light pollution[7]. In 2020, the International Dark-Sky Association (IDA) introduced 'Five Principles for Responsible Outdoor Lighting' to protect the nocturnal landscapes and night sky (Zielinska-Dabkowska, 2020). These IDA principles are described in Figure 3-6.

The Australian Government has developed National Light Pollution Guidelines for Wildlife (Department of the Environment and Energy, 2020). The aim of the guidelines is that artificial light will be managed so wildlife is:

1. Not disrupted within, nor displaced from, important habitat; and
2. Able to undertake critical behaviours such as foraging, reproduction and dispersal.

These Australian guidelines recommend:

1. Always using Best Practice Lighting Design (BPLD) to reduce light pollution and minimise the effect on wildlife; and
2. Undertaking an Environmental Impact Assessment (EIA) for effects of artificial light on listed species for which artificial light has been demonstrated to affect behaviour, survivorship or reproduction.

More details about the guidelines are provided in Appendix B.

Lights Out Toronto[8] is a public awareness campaign aimed at informing people of the dangers the urban environment poses to migratory birds. It encourages people to help reduce light pollution, which draws birds into the city, by asking them to turn out unnecessary lights at work and at home. The city works with several stakeholders including Fatal Light Awareness Program (FLAP), Building Owners and Managers Association (BOMA), Environment Canada, and bird advocacy groups. These stakeholders form a working group that determines the various best means of getting the 'lights out' message to the public.

3.6.2 Management of photobiology effects in New Zealand

There are no national guidelines for managing photobiology effects in New Zealand, probably because much of the country experiences relatively low light pollution levels (Ministry for the Environment and Stats NZ, 2019; Falchi *et al*., 2016a). The Ministry for the Environment (MfE) does acknowledge that light pollution is likely affecting mātauranga Māori and cultural practices, natural ecosystems, and biodiversity (Ministry for the Environment, 2018).

The Resource Management Act (RMA) does not include specific reference to managing environmental photobiology effects. However, there are sections in the RMA that can be used to support management of photobiology effects. This includes section 5, 7, 8, 17, 32 and 322.

There are some examples of regional or local authorities managing light pollution.

The Christchurch District Plan[9] includes the following objective and policies:

6.3.2.1 Objective – Artificial outdoor lighting and glare

a. Artificial outdoor lighting enables night-time work, rural productive activities, recreation activities, sport, entertainment activities, transportation and public health and safety while:
   i. managing adverse effects on residential, commercial, open space and rural amenity values;
   ii. areas of natural, historic or cultural significance and the night sky; and
   iii. avoiding interference with the safe operation of transport and infrastructure.

6.3.2.1.1 Policy – Enabling night-time activity while managing the adverse effects of artificial outdoor lighting

7 This includes the International Dark-Sky Association (IDA), Illuminating Engineering Society (IES) in the USA, the Commission for Dark Skies (CfDS) in the UK, The Light-Pollution Abatement Committee (LPA Committee) in Canada, the National Association for the Protection of the Night Sky and Environment (L'Association nationale pour la protection du ciel et de l'environnement nocturnes - ANPCEN) in France, Dark Skies Advisory Group (DSAG) in Switzerland and The Australasian Dark Sky Alliance (ADSA).

8 https://www.toronto.ca/311/knowledgebase/kb/docs/articles/city-planning/Infrastructure-and-Development-Services/bird-friendly-development-guidelines-lights-out-program.html

9 https://ccc.govt.nz/assets/Documents/The-Council/Plans-Strategies-Policies-Bylaws/Plans/district-plan/new-christchurch-district-plan/CH6-Nov2018.pdf.

a. Recognise and provide for artificial outdoor lighting for night-time activities and safety while managing its scale, timing, duration, design and direction in a way that:

i. avoids, remedies or mitigates adverse effects on the rest or relaxation of residents;

ii. or any areas of natural, historic or cultural significance;

iii. does not interfere with the safe operation of the transport network or aircraft;

iv. minimises unnecessary light spill into the night sky

The permitted light spill standards are lower for natural Open Space Zones (4.0 lux) than for most other zones. The effects of artificial outdoor lighting need to be considered and mitigated for range of ecological, cultural and amenity sites.

The New Plymouth District Plan also includes specific policies to prevent light pollution[10]:

Objective 1 - To ensure activities do not adversely affect the environmental and amenity values of areas within the district or adversely affect existing activities.

> Policy 1.1 - Activities should be located in areas where their effects are compatible with the character of the area.

> Policy 1.2 - Activities within an area should not have adverse effects that diminish the amenity of neighbouring areas, having regard to the character of the receiving environment and cumulative effects.

Objective 2 - To avoid, remedy or mitigate the adverse effects of light overspill and glare, noise, and the consumption of liquor on amenity values and health.

> Policy 2.1 - Light overspill should not result in adverse effects on amenity values and community health.

> Policy 2.2 - Activities should not result in adverse effects on amenity values, community health and safety due to glare from artificial light, flaring or reflected light.

In the New Plymouth District higher levels of light overspill are permitted in Open Space Environment Areas than in Residential and Rural Areas (10 lux). The Open Space Environment Areas have the same threshold as the Business and Industrial Areas (20 lux).

The Mackenzie District implemented a significant dark-sky conservation approach in 2012 by declaring the Aoraki Mackenzie International Dark Sky Reserve that covers an area of 4300 km^2 in the heart of South Island. The Aoraki Mackenzie Reserve remains the only dark sky conservation area in the Southern Hemisphere, and one of eight in the world. This conservation effort has been successful in drawing international attention, improved scientific skylight knowledge, and has helped develop tourism (IDA 2020). Creation of large dark sky spaces adjacent to urban areas is a potential solution to protect wildlife affected by light pollution.

The Martinborough Dark Sky Society (now the Wairarapa Dark Sky Society) has been established by the local communities to protect and enhance the view of dark skies and natural wildlife habitats of the area. With the support from IDA, the district council and Dark Sky Society in Martinborough have enhanced community awareness and encouraged central government agencies to adopt IDA's 3000K recommendation to alter their street and highway lighting plans. Moreover, the Martinborough Dark Sky Society is seeking to have an area greater than 1500 km^2 recognised as an International Dark Sky Reserve by the International Dark-Sky Association (IDA 2018).

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10 https://www.newplymouthnz.com/-/media/NPDC/Documents/Council/Council%20Documents/Plans%20and%20Strategies/District%20Plan/District%20Plan%20Management%20Strategy%20Feb%202018.ashx?la=en&hash=D650F9E78599A29B8C66531A13CC0568F863612C.

4 Light pollution

The moon is the main source of natural light at night, but additional light comes from natural atmospheric emissions (night glow), the stars, the Milky Way, and the false dawn (zodiacal light). During dark moonless nights, in the darkest parts of the sky, natural luminance is about 1.7 microcandelas per square metre (µcd/m^2). A microcandela is 1/1000th of the light output from one candle.

The amount of night-light also depends on atmospheric conditions. For instance, an overcast sky may result in a seven to ten times increase in light due to reflections and refraction (Falchi *et al*., 2016a).

Falchi *et al*. (2016a) notes that the view of the pristine sky begins to degrade when the brightness level exceeds 1.7 µcd/m^2. Above this brightness level, the visual impact from artificial lighting gradually increases. as described in Table 4-1.

Figure 4-2 shows the spatial distribution of light pollution in New Zealand, Australia and Indonesia.

Table 4-1 Types of visual impacts related to different levels of artificial sky brightness measured against natural brightness, which is set at 174 µcd/m^2.

Visual Experience	Colour on Figure 4-2	Artificial Brightness (µcd/M^2)	Ratio to Natural Night Light
Pristine sky	Black	<1.74	Less than 1%
Consider protection from future light increases	Grey	1.74-6.96	1-2%
Light pollution for astronomical purposes	Blues	6.96-55.7	8-32%
Parts of the night sky obscured, getting night glows	Greens	55.7-223	32-128%
Winter Milky Way no longer observable in winter	Yellow	223–445	128-256%
Milky Way not observable in any season	Orange	445–890	256-512%
Can start to see colours (both cones and rods active in human eyes) and the sky can look like permanent twilight	Red	890–1780	512-1020%
Increasing light and more and more features and colours visible	Magenta	1780–3560	1020-2050%
	Pink	3560–7130	2050-4100%
	White	>7130 (0.077 Lux)	>4100%

These light levels are still considerably lower than can be experienced at midday on a summer's day in New Zealand. The light intensity would be expected to measure in the region of 5000-10,000 Lux, even in the shade or on an overcast day, and 80,000– 100,000 Lux in the full sun. In contrast, the average office has a Lux of <1000 (Gibson undated). Note that one Lumen is equivalent to 1,000,000 microcandela (µcd).

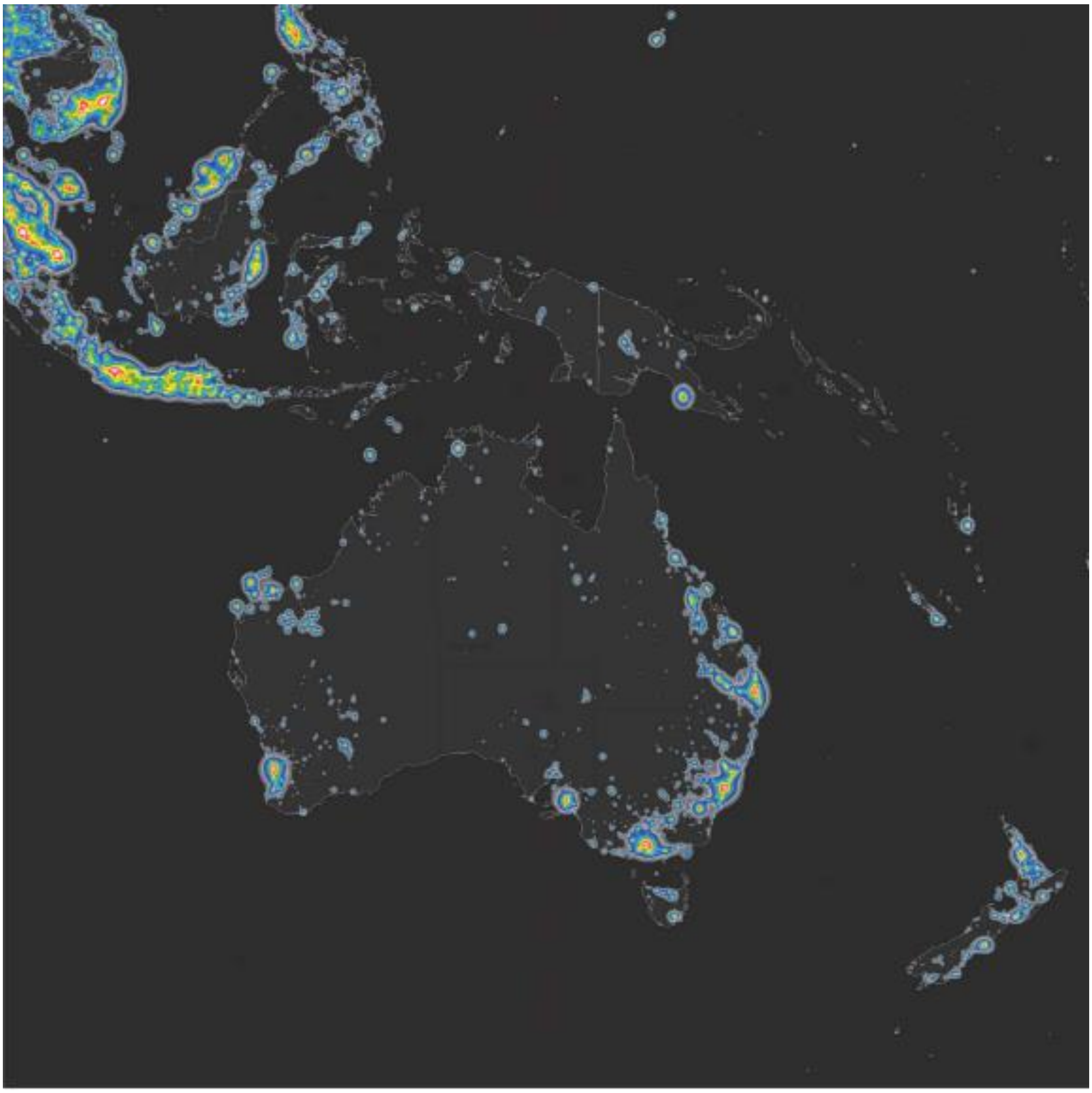

Figure 4-2 Map of artificial sky brightness for Australia, Indonesia, and New Zealand
The key to the colours is provided in Table 4-1. Colours other than black or grey indicate light pollution. Areas coloured red experience a permanent twilight. White, pink and magenta areas are the most light polluted.
(Source Falchi *et al*., 2016a).

4.2 Light pollution in Lower Hutt District

Images from the Suomi National Polar-orbiting Partnership satellite from 2014 showed that nearly 74% of the land area in North Island and 93% of land in the South Island had night skies that were either pristine or degraded only near the horizon (also refer to Figure 4-2).

Despite the low level of light pollution in most areas, Lower Hutt District was the second-largest area in lower North Island with high night-sky brightness levels (890–1780μcd/m^2). Light levels in the most urbanised part of Lower Hutt District, in a triangular area approximately between the western end of Petone, Seaview and Wingate, are such that it is no longer possible to view the Milky Way or many of the stars at night. Modelling shows that even in more rural areas, like Wainuiomata and along the coast, light emission from urban areas will obscure parts of the night sky and artificial light night glows will be visible (Figure 4-4).

These high light levels may pose a barrier for nocturnal avian species that fly between important native reserves such as the Belmont Regional Park, East Harbour Regional Park, Wainuiomata Scenic Reserve, Hayward Scenic Reserve and Korau Recreation Reserve. Light pollution also affects the lower 4km of the Te Awa Kairangi / Hutt River, which could affect aquatic species. Conversely, light pollution may attract some avian and aquatic species into areas that they would normally avoid (such as insects or fish attracted to light) (Figure 4-3).

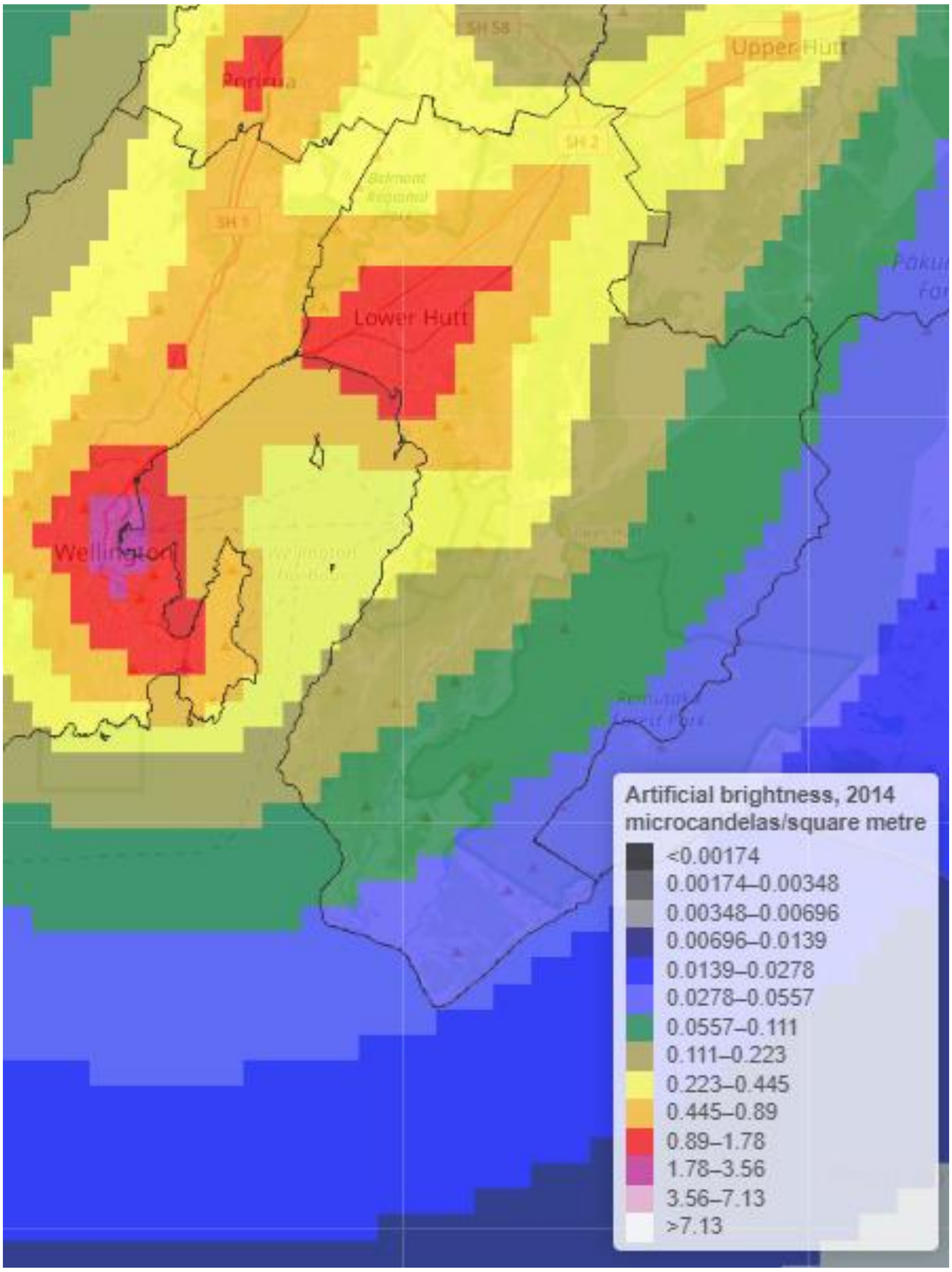

Figure 4-3 Artificial night sky radiance in the Lower Hutt District.
Based on data from May, June, September, October, November, and December 2014 (Source: Falchi *et al*., 2016b)

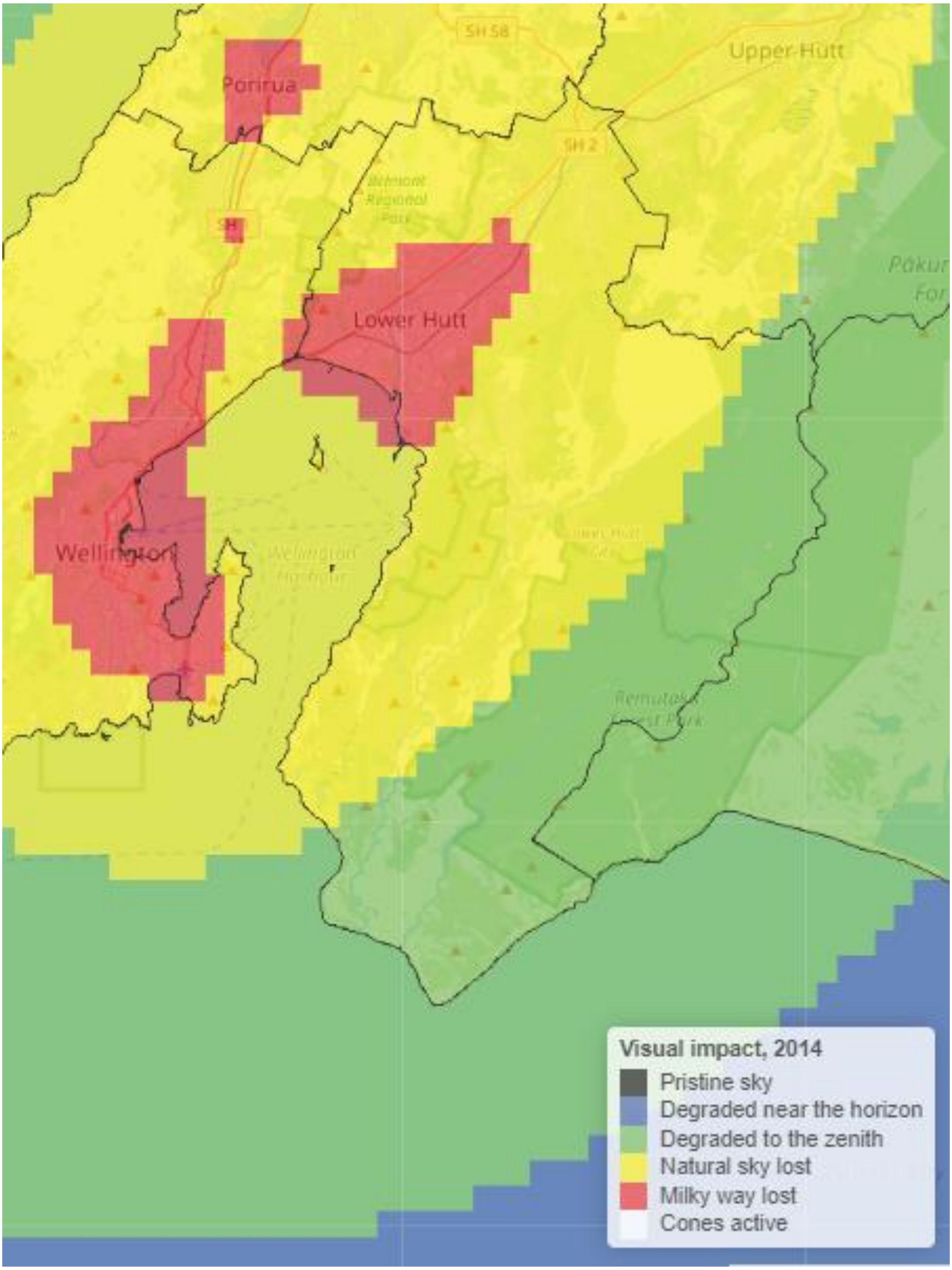

Figure 4-4 Visual impact of the light pollution in the Lower Hutt District.
Based on data from May, June, September, October, November, and December 2014 (Source: Falchi *et al*., 2016b)

5 Potential effects of light pollution on fauna

5.1 Perception of light by fauna

Campos (2017) showed that animals perceive light differently from humans. Most animals are sensitive to ultra-violet (UV)/violet/blue light. Some birds are sensitive to longer wavelengths in the yellow/orange range. Some reptiles can detect infra-red wavelengths. The sensitivity of wildlife to different light wavelengths is critical to assessing the potential effects of artificial light on wildlife (Figure 5-1).

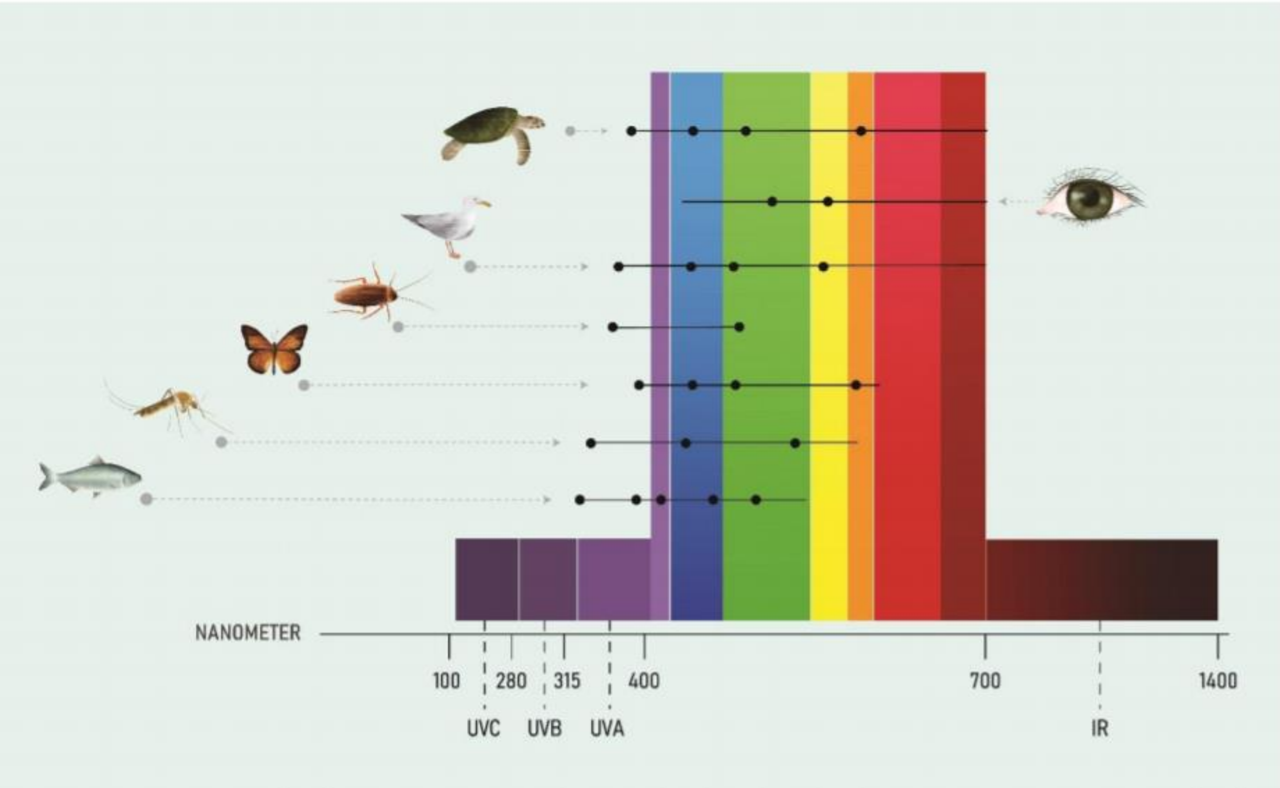

Figure 5-1 Humans and wildlife light wavelength perception ranges, shown by horizontal lines.
Black dots indicate reported peak sensitivities. UVA, UVB and UVC denote Ultra Violet A, B, and C, respectively and IR refers to Infrared (Source: National Light Pollution Guidelines for Wildlife Including Marine Turtles, Seabirds and Migratory Shorebirds, Commonwealth of Australia, 2020)

5.2 Native birds

Fifty-eight species of native birds have been recorded from the Lower Hutt District, and over 40% of these are classified as Threatened or At-Risk (Robertson *et al*., 2017). These birds inhabit a wide range of habitats, from native forests, river gravel beds, riparian margins, sandy and rocky shores, to offshore island. Some of these birds are international migrants, some migrate long distances within New Zealand, and many fly long distances to take advantage of seasonal food or breeding opportunities.

Of the 58 bird species recorded in the Lower Hutt District, 44 (76%) species disperse over varying distances. The rest of the species move through the landscape locally. Nearly half of the 58 species (25) are known to move about the landscape at night and could therefore be affected by light pollution (Table 1 in Appendix A).

The Australian Department of the Environment and Energy (DEE., 2020) found that lights can disorient flying birds, particularly during migration. Light pollution can hide their navigational aids (sun, moon and stars) and bright lights can attract birds causing them to divert from efficient migratory routes (death through exhaustion) or collide with infrastructure. This effect can be especially pronounced when visibility is poor, such as on foggy nights (APA, 2018). Attraction to artificial night lighting may result in other adverse effects to birds such as reducing fuel stores and delaying migration (Gauthreaux and Belser, 2006).

In Toronto, Canada, researchers found that many species of migratory birds travel at night and brightly-lit urban areas along their routes posed a serious threat. The birds become disoriented by the light and are drawn toward it. They then become trapped in the unfamiliar urban environment, which often results in the death of these birds when they fly into buildings[11].

Based on observations on oil platforms in the North Sea, Poot *et al*. (2019) suggested that birds could be attracted from up to 5 km with full lighting (30 kW). This study found that birds respond differently under field conditions to various colours of artificial light. The strongest reaction of migratory birds was to white and red light (long wavelength); there was a weaker reaction to green light (shorter wavelength); while the blue light (short wavelength) did not cause an observable effect on the birds' orientation during the study. Further, the birds apparently did not react to the infrared heat radiation > 680 nm. This led to the assumption that the visible (long wavelength) part of the spectrum (i.e. excluding the infrared part) causes the disorienting effect on migrating birds. The authors suggested developing bird-friendly lighting to reduce effects on nocturnally-migrating birds.

Dominoni *et al*. (2014) summarises some of the light effects on European birds which include extended hours of foraging activity of blackbirds (*Turdus merula*), earlier dawn chorus from songbirds, and earlier breeding of blue tits (*Cyanistes caeruleus*) and great tits (*Parus major*). In the laboratory, Dominoni *et al*. (2014) found that both the intensity of the light and the colour of the light affected bird activity, with more activity at greater light intensities. Green light at low light intensities caused less disturbance to daily activity patterns of blue tits compared to red or white light.

For many species, daylength is a cue to start breeding. Increased light can cause birds to nest much earlier (a month earlier in grasslands and wetlands, and up to 18 days earlier in forest environments in the USA) and this can cause a mismatch with food availability resulting in starvation. However, this effect may be offset by climate warming also advancing food availability (NASA, 2020).

Another study found increasing bird density closer to cities which raised concern regarding many birds congregating in a small area with limited resources, and higher mortality risks (cats, infrastructure collision). The increased bird density was detectable up to 200km from high light areas in the USA. This range may widen further due to increasing light pollution with the advent of LED lights, which are much brighter than the incandescent lights they replaced (APA, 2018).

In addition to behavioural changes, high intensity of artificial lights may cause blindness in birds by bleaching visual pigments (Verheijen, 1985). As a consequence of impaired vision, birds are less likely to identify visual details and there may be interference with the magnetic compass used by the birds during migration (Poot *et al*., 2008).

5.2.1 Coastal and seabirds

Most of the coastal areas in the Lower Hutt District have been developed and include roads and industrial and urban precincts. These areas are lit up with artificial lights for all (or most) of the night and this could affect coastal and seabird species.

The Australian Department of the Environment and Energy (DEE, 2020) found that blue penguin (*Eudyptula minor*) had a high risk of being disoriented by artificial light along roads resulting in a greater likelihood of being killed by motor vehicles, especially during the fledgling period (McLaren, 2018). Fledgling seabirds may not be able to take their first flight if their nesting habitat never becomes dark. Migratory shorebirds could get lost or diverted from the optimal route, or use less preferable roosting sites to avoid lights or conversely may be exposed to increased predation where lighting makes them visible at night (DEE, 2020).

In New Zealand, Neal (2020) reported increased mortality of Westland petrel fledglings after the introduction of new LED street lights through Punakaiki. Seabirds may also starve as a result of disruption to foraging, hampering their ability to prepare for breeding or migration. High mortality of seabirds occurs through grounding of fledglings as a result of attraction to lights and through interaction with vessels at sea (DEE, 2020; Rodríguez *et al*., 2017).

Migratory species including shorebirds are characterised by long life-spans and low reproductive success. As such, preserving the natural character of their breeding grounds remains highly important in the conservation of shorebird populations (Piersma and Baker, 2000). There is evidence that night-time lighting of migratory shorebird foraging areas may benefit the birds by allowing greater visual foraging opportunities (Santos *et*

[11] https://www.toronto.ca/311/knowledgebase/kb/docs/articles/city-planning/Infrastructure-and-Development-Services/bird-friendly-development-guidelines-lights-out-program.html

al., 2010). However, where nocturnal roosts are artificially illuminated, shorebirds may be displaced, potentially reducing their local abundance if the energetic cost to travel between suitable nocturnal roosts and foraging sites is too great (Dias *et al*., 2006; Rogers *et al*., 2006). Intermittent or flashing lights could flush out the shorebirds and force them to leave the area, especially if the light is persistent (DEE, 2020). Artificial lighting could also act as an ecological trap by drawing migratory shorebirds to foraging areas with increased predation risk (DEE, 2020; Colwell, 2010).

Further, artificial lighting affects daily activity pattern and habitat use of migratory birds, which are active during both day and night (Colwell, 2010). For instance, Dwyer *et al*. (2013) showed artificial light generated from a large industrial site significantly altered the foraging strategy of Common Redshanks within an estuary. The greater nocturnal illumination of the estuary from the industrial site allowed the birds to forage for extended periods using a visual foraging strategy, which was deemed a more effective foraging behaviour when compared to tactile foraging.

5.3 Native mammals

5.3.1 Bats

Long-tailed bats (*Chalinolobus tuberculatus*) are the only native terrestrial mammal recorded within the Lower Hutt District, and have a threat classification of Threatened-Nationally Vulnerable (O'Donnell *et al*., 2018; Table 2 in Appendix A). Long-tailed bats emerge from roosts shortly after dusk and return to these, or find another roost, before dawn.

In Hamilton (New Zealand), lighting appears to form a barrier to use of habitat by long-tailed bats with no bats occurring past a brightly lit bridge over the Waikato River (Dekrout, 2009; Le Roux and Le Roux, 2012). Bat activity is also correlated negatively with street light density (Dekrout *et al*., 2014). However, anecdotal reports suggest that at least occasionally long-tailed bats will forage around or above street lights (Connolly, 2013; Wildland Consultants, 2016; Smith el al., 2017).

Smith *et al*. (2017) looked at effects of land transport activities on bats in New Zealand, including the effects of light. They noted that orientation and movements through the landscape may be compromised for nocturnal species such as long-tailed bats due to light pollution. This could lead to injuries and mortality from collisions, including with moving vehicles, and increased exposure to predation.

Straka *et al*. (2019) showed that dense tree cover reduces the negative effect of street lamps (without UV) for urban wildlife fauna such as open-space foraging bats. Improving green cover has been suggested as a practical solution to minimising light pollution in urban areas.

For many bat species, daylength regulates their reproductive cycles and feeding behaviour. Photophobic species such as bats may be deterred from normal commuting behaviours by increased artificial light levels.

Kuijper *et al*. (2008) compared the commuting behaviour of pond bats (*Myotis dasycneme*) under dark and illuminated conditions. They found that artificial lights reduced the number of 'feeding buzzes' of bats (characteristic echolocation sounds produced when attacking prey) by 60% despite increased insect abundance beneath the lights. They also found that bats diverted from their normal commuting route, even at relatively low illumination levels.

Bristol University's 'Bats and Lighting' project (Stone *et al*., 2009) showed that slow-flying bats significantly reduced the normal use of hedgerows, and delayed their regular activities, under the influence of high-pressure sodium lights compared to unlit hedgerows. These behavioural changes are likely to have two effects on the long-term health of bats: (i) changing the flying-paths results in increased energy demands; and (ii) reduced foraging time due to altered commuting behaviour and delayed emergence from the roosts to the feeding sites. Similarly, LED and metal halide street lights also had a negative effect on the flight and feeding on slow-flying bats, while there was no significant observable effect on those behaviours of the fast-flying bat species.

More light-tolerant bats may be attracted to the aggregations of insect prey around white street lights (Blake *et al*., 1994; Rydell and Racey, 1995). This can put them at greater risk of collision with moving vehicles.

In summary, artificial illumination in urban areas is may create a barrier for bats, and change how they move through and use the landscape. This in turn can result in reduced population density of bats and increased vulnerability to collision impacts.

5.3.2 Sea mammals

Two species of marine mammals: New Zealand fur seal (*Arctocephalus forsteri*) and leopard seal (*Hydrurga leptonyx*; At Risk-Naturally Uncommon; Baker *et al*., 2019) have also been reported on the coast of Lower Hutt District (Table 2 in Appendix A). Both of these mammalian species are active during the night.

Little information could be found on the effects of light pollution on these species. There is information that light pollution affects their prey which may in turn affect how much energy fur seals and leopard seals need to expend while hunting. Berge *et al*. (2020) found that the normal working-light from a ship may disrupt fish and zooplankton behaviour down to a depth of at least 200 m across an area of >0.125 km^2 around the ship. Lights along the shore could have a similar effect.

Coastal light may also change where these species choose to come ashore and rest, and the location of breeding rookeries.

5.4 Lizards

Twelve lizard species have been recorded within Lower Hutt District, of which 9 (75%) are classified as 'Threatened' or 'At-Risk' (Hitchmough, 2016). Five of the 12 lizard species are predominantly nocturnal while the rest are active during the day, at dusk or dawn. Lizards occupy a wide range of habitat including forest, scrub, rocky areas and scree slopes, native and introduced plant species along the coast, in lowland and upland areas, urban gardens and pasture (Table 3 in Appendix A).

Because lizard species can occur within and very close to urban areas they will be subject to artificial light effects.

Gibson (undated) identifies that light is extremely important for keeping lizards in captivity, even for so-called nocturnal species, and that the quantity and quality can affect their activity, behaviour (including appetite and reproduction) and health. Lizards need a lot of light, up to 100 times the light available in an office room (on average >1,000 Lux). Lights need to produce natural 'daylight' wavelengths (approximately 5500 Kelvin). Specialist reptile lamps are designed to emit significant quantities of UVA (400–320 nm wavelength) and UVB (320–280 nm), to promote good health and appetite in reptiles and may enhance colour and vision, since many reptiles see UV wavelengths.

Perry *et al*. (2008) reported a lack of literature, experiment or records of systematic observational data for understanding the light pollution effects on lizards. This is slowly changing.

Taylor (2020) noted significant changes in lizard behaviour and physiology due to artificial light at night in an experimental study of urban wild-caught green anole lizard (*Anolis carolinensis*) in Texas. The lizards increased their foraging activity, while reducing their sleep. There was a difference in foraging activity between male and female lizards, with the former being more active and the latter less active. This may result in less interaction between the sexes resulting in decreased social communication and reproduction rates. Physiological changes included increased testes mass in males.

Brown anole lizards (*Anolis sagrei*), an abundant and invasive urban exploiter, showed increased growth and earlier egg-laying when exposed to increased artificial night lighting in the laboratory, compared to their natural state. Green anoles (*Anolis carolinensis*) had a similar response, but this may have been due to increased temperatures. Increased growth rates and reproductive output has the potential to increase competition with native lizard species in Miami, USA (Thawley and Kolbe, 2020).

In New Zealand we have one invasive lizard species that has become very abundant in some urban areas, the plague (rainbow) skink (*Lampropholis delicata*). Its main impacts are thought to be competition for resources with native lizards, the potential of disease transmission, and, because it is so abundant, sustaining higher predator densities. This species is not known to have established in the Greater Wellington Region as yet, but they are extremely good stowaways. It is not known how plague skinks react to increased light at night, and if they will pose a similar problem to the anole species in America.

New Zealand studies have shown that street lights result in increased gathering of nocturnal insects (Schofield, 2020; Pawson and Bader, 2014). Increased insect densities may attract lizards resulting in a greater risk of predation by mice (*Mus musculus*), rats (*Rattus* sp.), cats (*Felis catus*) and shorebirds (Towns and Elliot, 1996), and potentially also increased risk of being run over by vehicles.

Similarly to other species, bright night lighting may negatively affect the circadian (day-night) rhythm of lizard species, especially nocturnal species such as Pacific gecko (*Dactylocnemis pacificus*) and common gecko (*Woodworthia maculata*).

5.5 Invertebrates

Nine-hundred and thirty-seven taxa (973 species) of insects in 21 different orders were reported within Lower Hutt District. The main insect orders are Lepidoptera (butterflies and moths), Coleoptera (beetles) and Diptera (true flies such as horse-flies, crane flies and hoverflies) with 297, 200 and 160 different taxa reported respectively (Table 4 in Appendix A).

Because there are so many different species in this taxonomic group the potential for negative effects of artificial light pollution are greater than for any other group. Additionally, many orders also have very advanced visual senses (Desouhant *et al*., 2019). For instance, the visual perception in some species of butterflies and Hymenoptera (sawflies, wasps, bees and ants) is among the broadest of all animals, with visual perception ranging between IR (< 300nm) and UV (> 700nm) (Briscoe and Chittka, 2001). This means that these species are likely to be affected by any type of artificial light that assists human vision (Owens *et al*., 2020).

Owens *et al*. (2020) concluded that artificial lighting is a significant driver of insect declines through impacts on the development, movement, foraging, and reproductive success of insects, and increased predation.

Because of the high sensitivity to light, artificial light often affects the dispersal of nocturnal insects. In New Zealand, studies of aquatic invertebrates have shown that the shorter light wavelengths of light (UV, blue, green) are more visible to adult insects than longer wavelengths (yellow, orange, red). Freshwater adult insects are more attracted to cooler white LEDs (6500 K) that have a greater peak in intensity of blue light than warmer colour temperatures (3000 K). There was a 48% increase in insects trapping success by LED in comparison to the number of insects attracted to traditional high-pressure sodium lights (Schofield, 2020).

Because of the broad wavelength spectrum of LEDs simulating daylight (with a peak in blue), they attract a larger range of insect species including moths, butterflies and true flies, than conventional lamps, such as high-pressure sodium or metal halide (Royal Society of New Zealand, 2018; Pawson and Bader, 2013; van Langevelde *et al*., 2011). LED lights are recommended for use with insect traps as the light is very bright, attractive to a wide range of insect orders, energy efficient and compact (Pawson and Bader, 2014). In contrast, van Grunsven *et al*. (2014) showed that caddisflies are more attracted to traditional mercury vapour light sources than LED lights (Figure 5-2).

Therefore, when determining the type of light source to be used careful consideration should be given to the location of nearby habitat and the relative importance of the fauna likely to be impacted by artificial lighting.

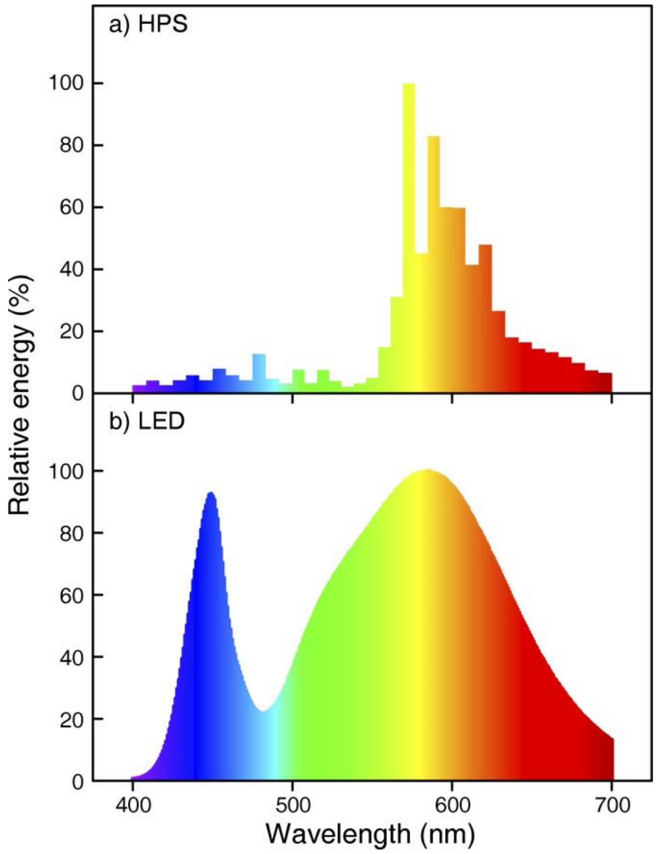

Figure 5-2 Relationships between relative energy and wavelengths emitted by two different light sources. (a) High-Pressure Sodium (HPS) lamp; and (b) Light Emitting Diode (LED) bulbs used for illuminating streets at night (Source: Pawson and Bader 2014)

Studies have shown that the effect of artificial lighting is more prominent within small spatial scales (Figure 5-3). For instance, single 70-W high-pressure sodium lamp attracts insects within a 20m radius of the light source (Degen *et al*., 2016; Merckx & Slade, 2014). However, the effective distance of an artificial light from its source may vary between 10m and 27m depending the type of light source and the insect taxa attracted by the light (Merckx & Slade, 2014).

Degen *et al*. (2016) showed that street lights limit moth dispersal, and that they impact male and female moths equally. As a consequence, public lighting might divide landscapes occupied by insects into many small habitats. Artificial lighting near hedges and bushes or field margins reduces the quality of these important habitat structures and affects moth movement between habitat patches.

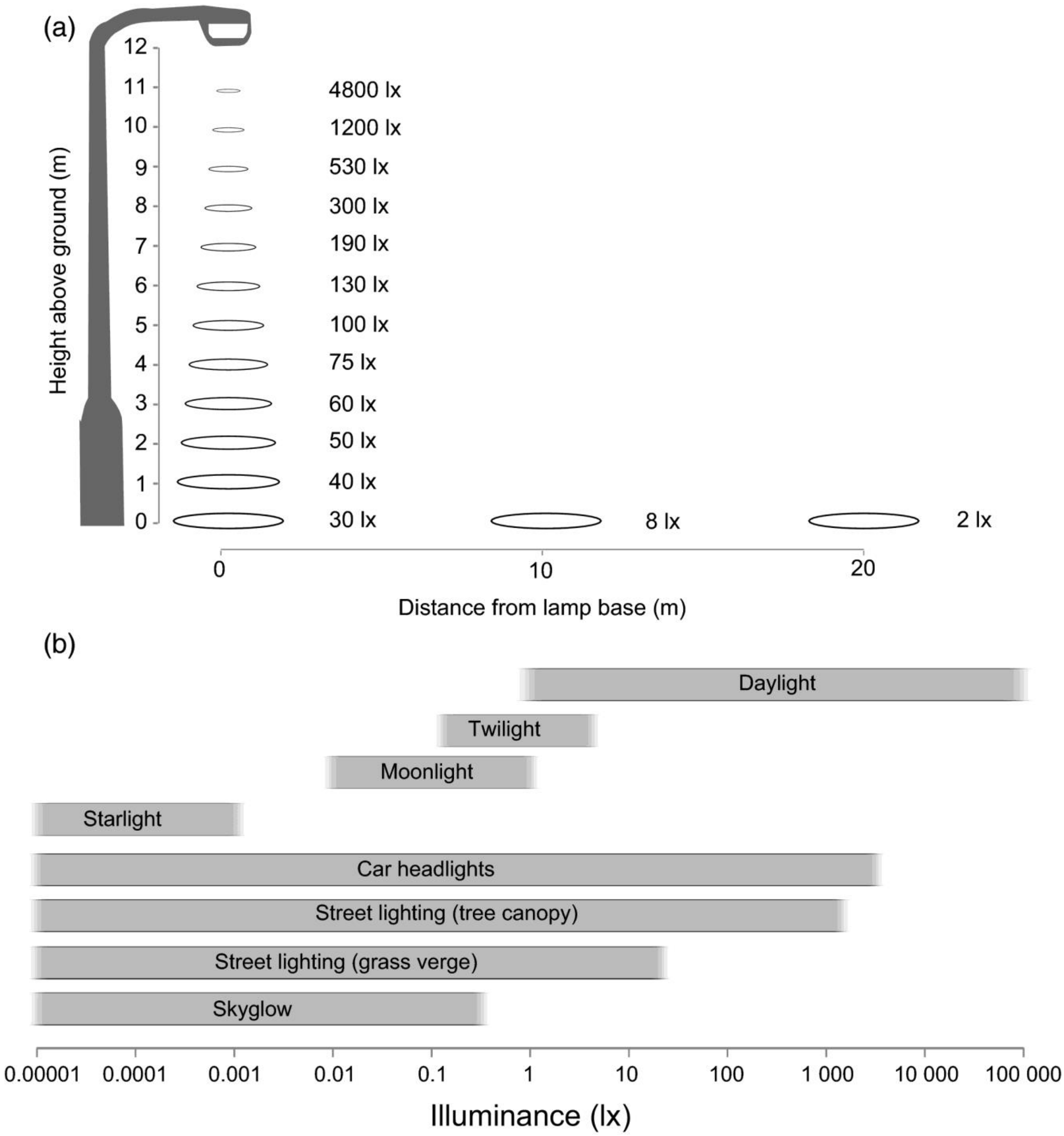

Figure 5-3 Effective distances of street light.
(a) Illumination measured in the horizontal plane from a typical street light (Phillips Cosmopolis, metal halide lamp). The intensity of light decays rapidly with distance to the lamp.
(b) comparison of measured illuminance from natural sources of light to artificial light sources – axis is on a logarithmic scale, and bars present approximate ranges based on field measurements
(Source: Bennie *et al*., 2016)

On larger (landscape) scales, artificial lights have significant effects on the orientation of dung beetles (*Scarabaeus satyrus*), which use the Milky Way for orientation. Dacke *et al*. (2013) described that dung beetles transport their dung balls along straight paths under a starlit sky, and they are disoriented when the Milky Way is not visible. View of the Milky Way can be lost under relatively low light pollution levels (refer to Table 4-1 and Figure 5-3).

It is essential for aquatic insects to be able to disperse across the landscape to colonise newly available or restored habitat, and to move between aquatic and terrestrial habitats in riparian areas. Artificial lights can have a severe negative effect over these large spatial scales for both colonising flights (Perkin *et al*., 2014) and in riparian areas (Manfrin *et al*., 2017; Meyer and Sullivan, 2013).

van Langevelde *et al*. (2017) reported that moths that were exposed to artificial lights reduced their feeding time by 58% - 82%, and also had reduced probability of starting to feed. Males of New Zealand weta (*Hemideina thoracica*) are observed less frequently at illuminated sites, compared to those were unlit, particularly under the full moon (Farnworth *et al*., 2018). Although the avoidance of illuminated sites by weta is likely an anti-predator response, the study suggested that it may affect other activities, such as feeding or mating.

Desouhant *et al*. (2019) argued that artificial lights reduce the efficiency of the bioluminescent signals (light flash against a dark backdrop vs light flash against an artificially lit backdrop. Therefore, the mating of species such as fireflies, and the feeding success of glow-worms, is likely to be negatively affected by light pollution. Firebaugh and Haynes (2016) experimentally described that the addition of artificial night lighting modifies the abundances and total flashing activity of fireflies. This in turn altered the courtship behaviour and mating between tethered females and free-flying males. Light pollution reduced flashing activity in a dark-active firefly species (*Photuris versicolor*), by about 70% as well as courtship behaviour and mating success in twilight-active species, such as *Photinus pyralis* (Owens *et al*., 2018; Firebaugh and Haynes, 2016).

Fruit flies (*Drosophila melanogaster*) are a diurnal (day-active) species. McLay *et al*. (2017) could show that ovipositing (i.e. laying at least one egg) and the number of eggs laid per female was reduced by 20% with exposure to low-intensity artificial light. For some invertebrate species artificial lights resulted in prolonged development times or premature emergence of larvae from eggs reducing development success (Moreau *et al*., 2017; van Geffen *et al*., 2014; Thakurdas *et al*., 2009). Immunity of insects to disease may also be affected by artificial lighting (Durrant *et al*., 2015).

Artificial light induced physiological effects have been observed in adult insects and are mainly related to the disruption of melatonin synthesis, which is a key hormone responsible for overall circadian regulation (Gaston *et al*., 2015). Melatonin (N-acetyl-5-methoxy-tryptamine) is mainly found in the head, eyes, optic lobe, and brain of insects (Hardeland and Poeggeler, 2003; Vivien-Roels and Pévet, 1993). In most insect species, melatonin is synthesised and released in darkness and suppressed at the presence of daylight (Hardeland & Poeggeler, 2003; Bembenek *et al*., 2005; Subala and Shivakumar, 2018). However, this pattern can be more complex in species such as the honey bee (*Apis mellifera*), which has several peaks of circulating melatonin at the beginning and end of the night (Yang *et al*., 2007). Disruption to melatonin synthesis is likely to affect several postembryonic processes such as moulting or metamorphosis, which may lead to immature growth of insects (Desouhant *et al*., 2019; Richter *et al*., 2000).

There is a large amount of scientific literature on negative consequences of artificial and night lighting on insect biology and behaviour. This is in part due to the fact that this is a very large and diverse group of species. Most of the studies described above were undertaken in laboratory settings, further studies are required to confirm whether there are, and the magnitude of, any widespread ecological, social and economic effects of artificial lighting on insects. The high level of light pollution in the Lower Hutt District, including loss of the view of the Milky Way in urbanised areas, is likely to be adversely affecting the diversity and abundance of insects and may also result in reduced abundance of insect predators.

5.6 Freshwater fish

Seventeen native freshwater fish native species have been reported within the Lower Hutt District of which nine of which (53%) have been classified as Threatened or At-Risk (Dunn *et al*., 2018). Twelve of the freshwater species are migratory but spend most of their lifetime in freshwater habitats. Ten of the migratory species are either catadromous (freshwater fish that spawn at sea) or amphidromous (freshwater fish migrate between sea and rivers but generally breed in freshwater) (McDowall, 1997). All of the reported freshwater fish species are mainly active at night, but some species such as longfin eel (*Anguilla dieffenbachii*) and common bully (*Gobiomorphus cotidianus*) can also be active during the day (author’s observation) (Table 5 in Appendix A).

Cullen and McCarthy (2000) reported that silver eels (*Anguilla anguilla*) were clearly deflected by artificial light during their migration the lower River Shannon in Ireland. New Zealand eels also show similar responses to artificial light. This deflecting behaviour has been clearly observed during spotlighting events for both longfin and shortfin eels (author’s observation). This light avoidance behaviour is likely to affect the distribution of eels in waterways with less suitable habitat in areas of high illumination. Particularly intense illuminations on bridges may act as a barrier to the upstream and downstream movement and migration of eels.

Avoidance of artificial light is also demonstrated by most of the other native freshwater fish species because these species are nocturnal (author's observation; McDowall, 1990). Artificial light is likely to restrict many of their activities, including feeding, and moving through the waterways.

Kurvers *et al*. (2018) showed that guppies (*Poecilia reticulata*) emerge faster from their refuge and spend relatively more time in brightly illuminated areas than unlit areas. Guppies have been found in urban streams in New Zealand. As such, it is likely that light pollution in urban streams results in more favourable habitat for exotic fish than native species, resulting in a shift in the composition of urban stream fauna.

In a study on the effects of artificial light on the fish community in Bushmans Estuary, South Africa, Becker *et al*. (2013) found that artificial light benefited predatory fish (piscivores) by attracting and concentrating fish and also benefited predators that hunt by sight. More successful fish predation has the potential to reduce the stocks of prey fish populations within urban estuarine and coastal waters. New Zealand estuaries are significant spawning habitats of amphidromous fish. Artificial illumination at estuaries and along the coast may increase the vulnerability of juvenile amphidromous fish to marine predators. The study recommended that lighting should be minimised around coastal infrastructure and the use of red lights, which have limited penetration though water.

Brüning *et al*. (2016 and 2018) have shown that artificial night-lights have significant impacts on fish physiology. They studied melatonin excretion in European perch (*Perca fluviatilis*) and in roach (*Rutilus rutilus*), under different wavelengths during the night (blue, green, and red) and also at different light intensities. Their findings showed that artificial lighting causes significant decreases of melatonin levels regardless of the colour of light, with blue light resulting in the least effect. The results of these studies also showed that melatonin concentrations in fish drop significantly under nocturnal white light even at light intensities as low as 1 lux. There was also evidence that artificial light could adversely affect reproductive hormone production in female perch. These studies suggest that light pollution not has only the potential to disturb the melatonin cycle but also the reproductive rhythm, and may therefore have implications on whole species communities.

5.7 Ecosystem scale effects

Secondi (2020) described that cloud cover extends the effect of artificial illumination further away from urban areas through reflection and refraction. Extended effects of light pollution may lead to changes in semi-urban and rural ecosystems, including on primary production, species distribution patterns, trophic interactions and local biodiversity. Thus, this next section briefly discusses light pollution effects from the ecosystem perspective.

5.7.1 Primary production

Plant communities play an important role in the ecosystem as primary producers. Bennie *et al*. (2016) described that prolonged exposure to artificial light is likely to induce early budburst (emergence of leaves), retention of leaves on deciduous plants and increased flowering. In addition, plants may potentially be adversely affected by the reduced darkness that is crucial for repair and recovery from environmental stresses in particularly in the urban areas.

In lake ecosystems worldwide, artificial light has contributed to increasing the relative biomass of blue-green algae and submerged macrophyte leading to eutrophication (Xu *et al*., 2019; Smith, 2013). Similarly, Gregory (1980) reported that additional light increases colonisation of algae, gross primary production, net community primary production, community respiration, production /respiration ratios and altered community structure of diatoms, in stream ecosystems.

5.7.2 Species distribution

The effect of artificial light at night potentially impacts species distribution patterns at local scales, as well as over large spatial areas. The effect of light pollution at local scale was evident in the distribution of isopods (*Tylos spinulosus*) living in sandy beaches of north-central Chile. Isopods burrow in the sand during daylight and emerge at night to migrate down-shore. Field observations showed that the isopod abundance significantly decreases near light sources, restricting their tidal distribution range (Duarte *et al*., 2019). In addition, attraction of flying insects to light sources (Schofield, 2020; Pawson and Bader, 2014) and repulsive effect of bright lights on shorebirds (DEE, 2020) also showed the effect of artificial lights on species distribution at small spatial scales.

Distribution of birds have been affected by artificial illumination at large spatial scales as well. Cabrera-Cruz *et al*. (2020) found evidence showing broad-scale avoidance of bright areas by migratory birds during stopover. Another study found that shorebirds avoided their usual nocturnal habitats, and roosted further inland, due to artificial illumination in coastal areas (Dias *et al*., 2006; Rogers *et al*., 2006).

Bliss-Ketchum *et al.* (2016) explained that artificial lighting is likely a barrier to the movement of wildlife. Weekly observations, looking at footprint tracks in sand, found that Columbia black-tailed deer (*Odocoileus hemionus columbianus*), deer mouse (*Peromyscus maniculatus*) and opossum (*Didelphis virginiana*) were less likely to use under-road passage bridges in Portland, USA if these were brightly lit. This suggests that artificial lights at night can cause potential habitat fragmentation for some wildlife in urban areas.

Illuminated areas may lead to disorientations in flight paths of nocturnal species such as long-tailed bats (*Chalinolobus tuberculatus*) and in the migratory paths of the freshwater fish (Smith *et al*., 2017; Cullen and McCarthy, 2000). Overall, the impact of artificial lights at night has become a potential impediment to both short-term and long-term natural dispersal of urban wildlife, and could result in changes in their ecosystem-wide distribution.

5.7.3 Trophic relationships

Food webs model important ecosystems functions including energy transfer and nutrient cycling. A simple food web is shown in Figure 5-4.

Impacts on one species have the potential affect multiple species within the food web. For example, reduced plant growth can lead to starvation of all the animal species connected to this particular food web. Reduction in the population of the top predator can result in more pest animals and damage to food crops. These large effects are known as trophic cascades.

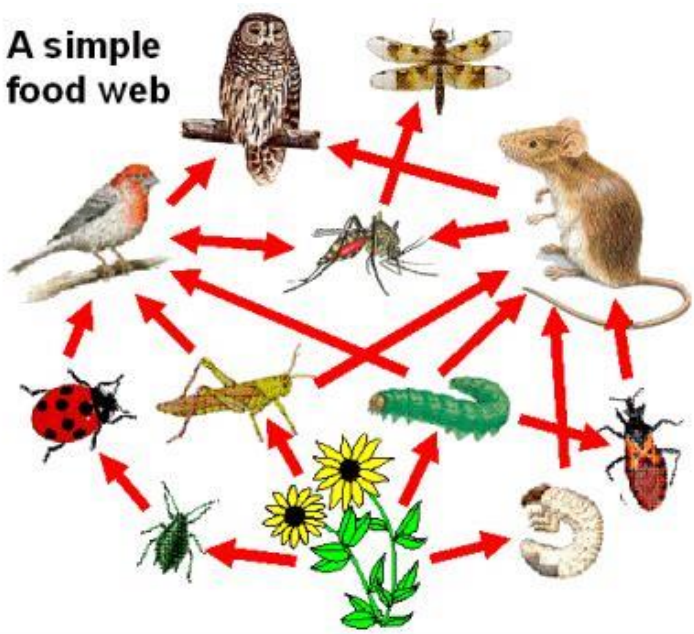

Figure 5-4 Example of a simple food web

Bennie *et al*. (2016) used monochromatic amber light at night, which has a similar effect to that of low-pressure sodium vapour (LPS) street lighting, in an experiment with lotus (*Lotus pedunculatus*) and pea aphids (*Acyrthosiphon pisum*). Low intensity light significantly suppressed the flowering of lotus in spring and early-summer, leading to a seasonal reduction in the density of pea aphids. This experiment suggested that light pollution potentially causes a negative effect on the pollinators via suppressing the physiology of their host plants.

Knop *et al*. (2017) looked at nocturnal pollinators and plant reproductive success. They found that there was a 62% reduction in pollinator visits to plant communities, compared to dark areas. This resulted in a 13% reduction in the yield of fruit, regardless of the pollinator visits during the day time. Less fruit can lead to less food availability and fewer plants in the future.

Parkinson *et al*. (2020) conducted a 2-year field study to investigate the impact of light pollution on freshwater-terrestrial food webs by installing streetlights in a historically unlit riparian area adjacent to an agricultural drainage ditch. The study compared the abundance and community composition of emerging aquatic insects, flying insects, and ground-dwelling arthropods against a dark control site. Study results showed that abundance of several night-active ground-dwelling predators (*Pachygnatha clercki, Trochosa* sp., Opiliones) increased under artificial light at night and their activity was extended into the day. Conversely, the abundance of nocturnal ground beetles (Carabidae) decreased under the influence of light at night. The changes in composition of riparian predator and scavenger communities have potential to cascade through the riparian food web, including links between aquatic and terrestrial domains. This effect is likely to increase due to the increasing numbers of streetlights that are installed along shorelines of freshwater habitats.

The New Zealand freshwater fish communities are largely insectivorous (McDowall, 1990). As such, changes in the abundance of insects will affect these species. Caddisflies is the largest order of benthic macroinvertebrates found in urban streams (Collier and Winterbourn, 2000). Schofield (2020) showed that large numbers of caddisflies were attracted to artificial lights and that these short-living adult insects may not return to the streams for mating as a consequence of predation or disorientation (Schofield, 2020; Pawson and Bader, 2014). This will lead to a shortage in food supply to freshwater fish (Collier and Winterbourn, 2000). The effect of light was shown to extend about 50 metres from the source (Schofield, 2020).

5.7.4 Biodiversity

Light pollution related effects may have temporary or long-term consequences for biodiversity at varying spatial scales from individual habitats to ecosystems. The local diversity of species and the health of those species will differ according to how species react to increased artificial light. Gaston and Bennie (2014) predicted that illuminated areas would have reduced animal populations compared to darker areas, potentially resulting a loss of local biodiversity in more urban areas. The barrier effect of artificial light at night may also isolate populations, impacting on their genetic diversity, susceptibility to disease, and access to resources (Bliss-Ketchum *et al*., 2016). In contrast, temporary increases in local species diversity can occur near illuminated areas because of light-loving flying-insects and fish (Pawson and Bader, 2013).

The long-term effects of light pollution on biodiversity are more widespread and complex than the temporary effects. For instance, light pollution related physiological impacts such as the impaired reproductive success may lead to the population decline and eventual local extinctions (Robert *et al*., 2015). Artificial illumination potentially drives hormonal defects such as melatonin synthesis failure, which negatively impacts embryonic development, growth regulation and immunity resulting in reduced health of the affected fauna (Durrant *et al*., 2015; Gaston *et al*., 2015). Compromised health of fauna consequently would result in population declines and could result in extinction of species over time.

Impacts of light pollution also occur at community level such as the suppression of pollinator insects and ecosystem-wide consequences including eutrophication of water bodies (Xu *et al*., 2019; Knop *et al*., 2017). Increased artificial light can negatively affect the diversity of native urban fauna, and also favour light pollution tolerant invasive species.

Stone *et al*. (2012) explained that artificial lighting is a key biodiversity threat, while producing 1,900 million tonnes of CO_2 emissions globally, which is more than three times of that produced by aviation. However, the need to meet climate change targets has led to a global increase in energy-efficient light sources such as high-brightness light-emitting diodes (LEDs). Despite the energetic benefits of LEDs, their ecological impacts have not been tested adequately. Therefore, further research remains an essential element in mitigating the adverse effects of artificial night lighting on urban wildlife fauna and their ecosystems.

6 Knowledge gaps and future research

It was not possible within the scope of this project, to undertake exhaustive literature reviews for all species known to occur in the Lower Hutt District. Little is known about the actual effects of outdoor lighting on native New Zealand fauna, and in many instances, it was difficult to find information on related overseas species. It may be possible that further desktop investigations of the photobiological effects on species related to New Zealand species may identify other positive or adverse effects. However, many species are unique to New Zealand and their behaviour may or may not be similar to that noted for overseas species.

Although the body of work on photobiological effects on fauna is increasing there are still many areas where there is a lack of scientific research which poses a major limitation in understanding, controlling and mitigating the adverse ecological effects of light pollution. This section briefly outlines the aspects that require further research.

The following knowledge gaps and potential research avenues on the effects of light pollution on urban wildlife in New Zealand were identified:

> Information on how particular native species respond to artificial light at night. There are many species that could be studied, but initially the focus could be on:
  - Native bats - are they adversely affected by night lighting and do they require dark corridors to move around the landscape?
  - Kiwi – will night lighting deter kiwi from entering urban areas. How will this affect kiwi spreading out from the Orongorongo Valley?
  - Shore and sea birds – can lighting in the coastal area be improved to provide better coastal habitat?
  - Migratory fish – is lighting near waterways an impediment to native fish feeding and migration? How can lighting be modified to reduce such effects?
  - Native invertebrate pollinators – what are the key nocturnal pollinators and are they adversely affected by night lighting? In turn how does this affect the plant species that rely on these pollinators?
  - Lizards – are native lizard species (nocturnal and diurnal) adversely affected by artificial lighting on their habitats?

> How does artificial light at night affect native plants, and plant cycles? Impacts on native plants will affect native fauna in turn,

> Which types of lighting have the least adverse effects on fauna and how to resolve the issue if different colours of lighting result in opposing effects for different species (e.g. blue light more attractive for invertebrates but possibly not attractive for birds)

> Confirm whether the effects of specific light sources (e.g. LED) on urban wildlife are similar for New Zealand native species as for their overseas counterparts.

> The effect of artificial night life on stream habitats including the interactions between in-stream, riparian and dry-land fauna.

> How does light pollution affect how and when fauna move through the landscape?

> Behavioural changes in common native species, such as tui and bellbird. Do they start singing earlier under artificial light than in darker areas, do they start nesting earlier and/or have a longer nesting season?

> How far does artificial lighting penetrate into forest margins and riparian areas?

> Potential technological and engineering solutions to minimise the impact of artificial light on urban wildlife.

> How to best increase public awareness and participation in preventing light pollution.

> Policies for controlling and preventing light pollution.

7 Light management options

Provision of lighting at night will always need to balance the adverse effects on fauna and ecosystems with human safety. Reducing adverse effects of night lighting on fauna will most likely require a mix of district wide applicable methods (e.g. minimising upward light shine) and specific requirements for special areas (e.g. fauna rich areas). This section summarises some potential light management options.

7.1 Lighting objectives and best practice guidelines

The Australian National Light Pollution Guidelines for Wildlife (DEE 2020)[12] sets out lighting objectives and best practice guidelines to help reduce sky glow and minimise the effects of artificial light on wildlife (reproduced in full in Appendix B).

The objectives are as follows:

> At the outset of a lighting design process, the purpose of artificial lighting should be clearly stated and consideration should be given as to whether it is required at all.

> Exterior lighting for public, commercial or industrial applications is typically designed to provide a safe working environment. It may also be required to provide for human amenity or commerce. Conversely, areas of darkness, seasonal management of artificial light, or minimised sky glow may be necessary for wildlife protection, astronomy or dark sky tourism.

> Lighting objectives will need to consider the regulatory requirements and the standards relevant to the activity, location and wildlife present.

> Objectives should be described in terms of specific locations and times for which artificial light is necessary. Consideration should be given to whether colour differentiation is required and if some areas should remain dark – either to contrast with lit areas or to avoid light spill. Where relevant, wildlife requirements should form part of the lighting objectives.

> A lighting installation will be deemed a success if it meets the lighting objectives (including wildlife needs) and areas of interest can be seen by humans clearly, easily, safely and without discomfort.

> The following provides general principles for lighting that will benefit the environment, local wildlife and reduce energy costs.

Best Practice lighting guidelines

Natural darkness has conservation value in the same way as clean water, air and soil and should be protected through good quality lighting design.

Simple management principles can be used to reduce light pollution, including:

1. **Start with natural darkness and only add light for specific purposes.**
2. **Use adaptive light controls to manage light timing, intensity and colour.**
3. **Light only the object or area intended – keep lights close to the ground, directed and shielded to avoid light spill.**
4. **Use the lowest intensity lighting appropriate for the task.**
5. **Use non-reflective, dark-coloured surfaces.**
6. **Use lights with reduced or filtered blue, violet and ultra-violet wavelengths.**

Appendix B includes examples of lighting placement and further details on the best practice guidelines.

12 https://environment.gov.au/biodiversity/publications/national-light-pollution-guidelines-wildlife

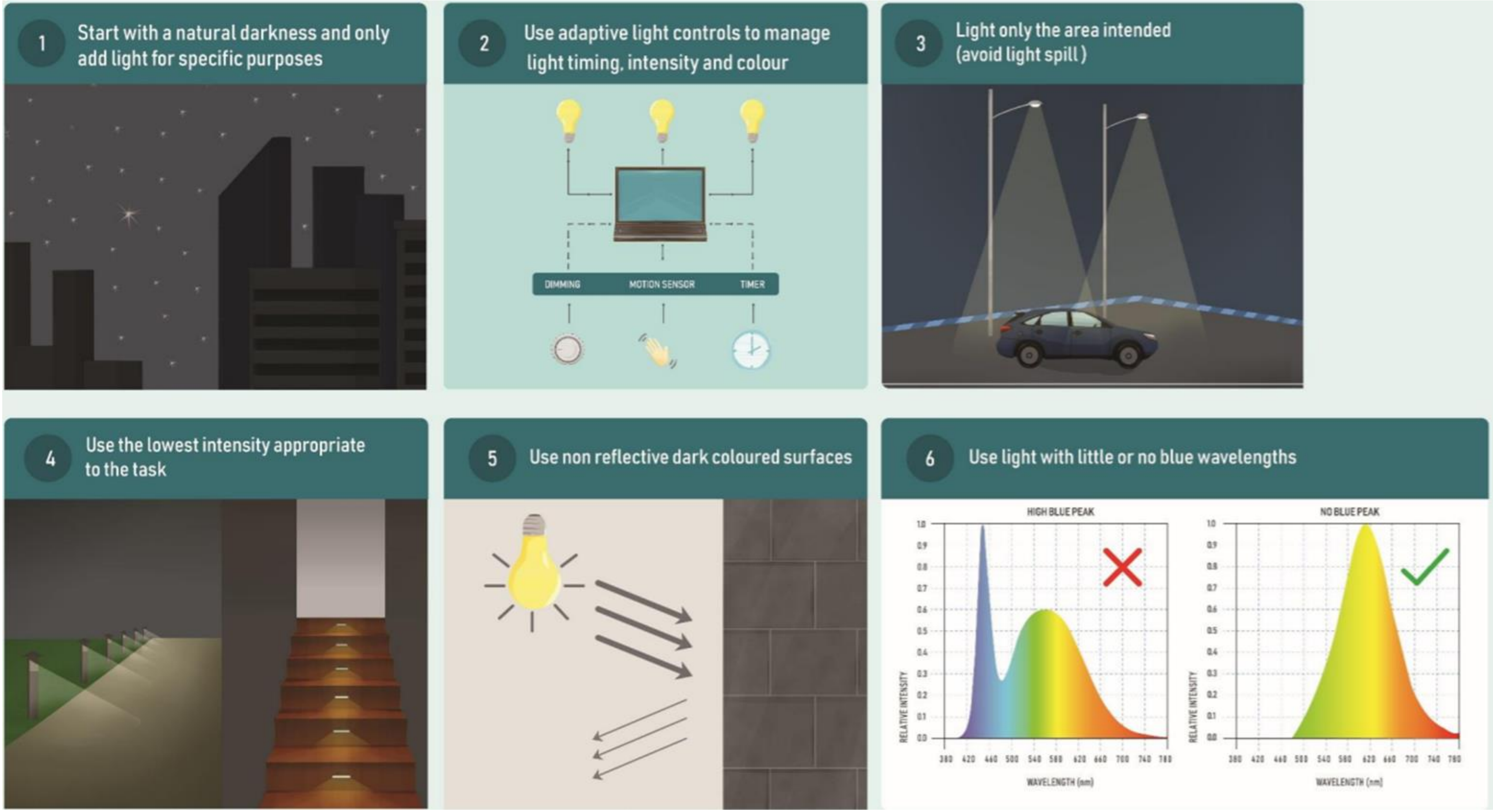

Figure 7-1 Illustration of best practice lighting design principles (Source: DEE 2020)

7.2 Options for Lower Hutt District

The following is a non-exhaustive list of how the adverse effects of lighting on fauna could be reduced within Lower Hutt City.

- Adopt objectives and best practice guidelines for external lighting similar to those developed for Australia.
- As part of lighting maintenance, progressively replace street lights and other council managed light sources with lights that adhere to the best practice guidelines for external lighting.
- Within the city encourage landowners and businesses to turn off all external building lights between specified hours. Within buildings encourage use of motion sensor light switches. All exterior advertising should be unlit between specified hours. The Lights Out Toronto project (Section 3.6) could be a useful programme to investigate.
- Carefully consider the placement of street lights and other lights in relation to ecological features such as rivers, forest margins and the coastal environment. It may be possible to reduce adverse effects on fauna by increasing the distance of lights to these features (e.g. mayflies are not attracted to lights more than 50 metres away).
- Ensure that light sources are in the blue rather than orange spectrum as this seems to cause less effects for most vertebrate fauna, but not invertebrate fauna (although information for vertebrate fauna is variable).
- Set street lighting at least 20 m away from waterbodies and ensure that these are in the orange part of the light spectrum.
- Consider including District Plan Dark Sky provisions, similar to those for the MacKenzie Basin, for certain activity areas or types of habitat. For instance, aim for dark skies for the Wainuiomata water catchment, the native forest areas in the Orongorongo catchment, parts of Belmont Regional Park, the Brookfield Outdoor Education Centre, or identified semi-urban ridgelines. In these areas lighting should either be kept to a minimum, or type of lighting used should minimise upward lighting and emit the appropriate colour of light.
- Consider including District Plan provisions that manage light sources near sensitive ecological features such as waterways, coastal areas, or large and continuous areas of native habitat. Identify ways to create or ensure that there are 'dark' corridors linking between these areas.
- Work with secondary (citizen science) and tertiary institutions to set up experiments or investigate the effects of light on particular species of fauna within Lower Hutt District.

8 Conclusions

Population growth and urbanisation of Lower Hutt District has gradually increased and is predicted to carry on increasing. This will likely result in the increased use of outdoor lighting at night.

More than 1,000 native species are known from the Lower Hutt District. These mostly comprise invertebrate species (937), but also birds, freshwater fish, lizards and mammals.

The current levels of artificial light, especially in the more densely populated areas of the city, are such that it is no longer possible to see the Milky Way at night. Even the more remote areas of the District, such as Wainuiomata, are affected by light pollution, which can be worse on cloudy nights when light is more reflected and refracted. Thus, it is highly likely that fauna within the district is affected by artificial light.

Some of the fauna within the district are only active during the day, but many can be active during both the day and the night. A number of nocturnal species are also present. Additionally, a number of the species in the Lower Hutt District are known to move long distances, including at night. Nocturnal species and those that migrate at night are likely to be most susceptible to the effects of light pollution.

There five main types of outdoor lighting available. These vary in their electricity use, light and heat output, and colour of the light output. Different species react differently to different colour outputs. As a general rule, lighting colour towards the orange end of the spectrum are perceived as warmer and more similar to sun-light, and are thought to pose fewer issues for humans and other fauna species.

The focus of this study was on the effects of lighting within the visible, light spectrum (to humans) on fauna. Potential effects on fauna include:

> Changes to how fauna move and use a landscape.
> Changes to the circadian clock and how active fauna are on a daily, seasonal, or yearly basis.
> Affect visual perception of fauna.
> Changes to the rate or start of development or growth.
> Attraction to or repelled by artificial light.
> Changes to plant growth with subsequent impacts on fauna.
> Ineffective bioluminescence (e.g. flash of a firefly) reducing mating or feeding opportunities.

There are some international policies on the management of light pollution, however there are no national standards in New Zealand. Parts of the country (the MacKenzie Basin and the Wairarapa) are striving to maintain or improve the darkness of the night, and some district plans include policies to manage the effects of outdoor lighting – including on fauna and natural areas.

The research on effects of artificial light on fauna can be confusing and conflicting. For instance, some studies find that red coloured lights attract birds more or result in greater levels of activity compared to green or blue-tinged lights. Other research points to increased sea-bird attractiveness when street lights were changed to more blue-tinged LED lights. Light spill effects could be detected up to 200 km away from densely urbanised areas of the USA. Increased light at night could affect bird behaviour, including earlier breeding, and a resultant a mismatch with food availability and starvation. Shore and seabirds appear to be especially prone to the effects of lights at night. This may be because many feed or migrate at night. Effects on these species can include failure to fledge, disorientation during flight, using less optimal roosting areas, disrupted foraging, and interactions with vehicular traffic.

There is some evidence that areas of high light intensity act as barriers for our native long-tailed bat, and may also increase their susceptibility to being struck by vehicles if they are hawking for insects beneath street lights. Overseas research also reports effects on bat species use of habitat and changes to behavioural patterns.

Little information could be found on the effects of light pollution on the two species of marine mammal that might use the coastal shore, or on how New Zealand species of lizard react to increased illumination of their habitats.

There are many different taxa of invertebrates and many ways that these invertebrate groups react with artificial lights. Research of some aquatic species in New Zealand has shown that the shorter light wavelengths of light (UV, blue, green) are more visible to adult insects than longer wavelengths (yellow, orange, red). The freshwater adult insects are more attracted to cooler white LEDs (6500 K) that have a greater peak in intensity of blue light than warmer colour temperatures (3000 K). Street lighting can create barrier for flying nocturnal insects, may make adjacent habitat unsuitable, or reduces the time that nocturnal insects spend feeding. Some invertebrates navigate using observations of the Milky Way which can be obscured by artificial light at night. For some day-active insects, increased night lighting also resulted behavioural changes and reduced breeding success.

All of the seventeen native fish species known from the Lower Hutt District are nocturnal, and most of them also migrate up and down waterways. It could be shown for some species that brightly lit water was a barrier for movement and feeding. Increased light at night may also favour introduced species over native species, and may make some species more susceptible to being preyed on.

The reported scale of increased light effects can extend over 200 km and can include ecosystem scale effects including changes to primary production and plant growth, changes in species distribution and movement through the landscape with resultant changes in populations, and changes to interactions and abundance of species within a food web, and temporary or long-term consequences for biodiversity.

Information on the effects of artificial light and light pollution was not found for many of the species that occur in the Lower Hutt District. A number of potential research avenues have been suggested. These should generally be more field-based, although literature research may still contribute additional information to that provided here.

Management of effects could include the adoption of lighting objectives and best practice principles, gradual replacement of lighting infra-structure with less light-polluting option, encouraging landowners to switch off lights at night, careful selection of the colour of the light to reduce effects on local fauna, and provisions in the District Plan for dark sky areas and placement and type of lighting close to natural features.

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APPENDIX

A

FAUNA RECORDED WITHIN LOWER HUTT DISTRICT

Table 1. Bird species reported in Lower Hutt District

Species	Common Name	National Threat Classification	Trait with light (d/n/c)	habitat	Migratory pattern[13]
Acanthisitta chloris	North Island rifleman	At Risk-Declining	Diurnal	Mature forest, especially beech, kauri, kamahi and podocarp forest	Not migratory
Anas gracilis	Grey teal	Not threatened	Nocturnal and diurnal	Shallow freshwater lakes, lagoons and swamps with extensive marginal cover and brackish water	Nomadic (finding more favourable habitat) and seasonal migration
Anas superciliosa	Grey duck	Threatened-Nationally Critical	Diurnal and nocturnal flights	Forested headwater catchments and away from human settlements	Nomadic (finding more favourable habitat) and seasonal migration
Anthornis melanura	Bellbird	Not threatened	Diurnal	Native and exotic forest, scrub, farm shelter belts, urban parks and gardens	Seasonal migration
Anarhynchus frontalis	Wrybill	Threatened-Nationally Vulnerable	Diurnal, and nocturnal flights	Inter-tidal mudflats in harbours and estuaries, braided riverbeds, local shell banks, beaches and pasture	Migratory within NZ
Anthus novaeseelandiae	New Zealand pipit	At Risk-Declining	Diurnal	Coastlines and rivers, alpine areas, wetlands, farmland and open shrublands, and tussock grasslands	Seasonal migration (altitudinal)
Apteryx mantelli	North Island brown kiwi	Threatened-Nationally Vulnerable	Nocturnal	Native and exotic forests, scrub, rough farmland	Long-range dispersal
Ardea modesta	White heron	Threatened-Nationally Critical	Diurnal	Harbours and estuaries, freshwater wetlands, high country lakes	Seasonal migration (breeding) (possible international vagrant)
Botaurus poiciloptilus	Bittern	Threatened-Nationally Endangered	Diurnal and nocturnal	Raupō-fringed lakes, spring-fed creeks, areas of rank-grass along paddock/drain edges	Long-range dispersal

[13] There are different types of bird movement. They have been categorised as follows:

- Not migratory – no seasonal or hormone induced movement of individuals or flocks of birds
- Long-range dispersal – juvenile birds moving away from natal territories
- Seasonal migration – individual birds moving around the landscape to take advantage of different or seasonal food sources (e.g. different fruiting species, or moving to warmer altitudes to forage on insects, or moving to a particular nesting area)
- Nomadic – flocks of birds moving en-mass to find more favourable habitat (e.g. the pond has dried up so move to a different waterbody)
- Migration – hormone induced movement of individuals or flocks of birds; can be within NZ and/or international

Species	Common Name	National Threat Classification	Trait with light (d/n/c)	habitat	Migratory pattern[13]
Calidris canutus	Lesser knot	Threatened-Nationally Vulnerable	Diurnal and nocturnal	Large harbours and estuaries	Migratory - international
Charadrius bicinctus	Banded dotterel	Threatened-Nationally Vulnerable	Diurnal and nocturnal	Harbours and estuaries, coastal lagoons and beaches, lightly vegetated riverbeds, outwash fans, herbfields, and farmland	Migratory (including international)
Chlidonias albostriatus	Black-fronted tern	Threatened-Nationally Endangered	Diurnal, and nocturnal flights	Braided channels of inland rivers, farmlands, scrub and tussock, coastal areas, harbours, estuaries and lagoons	Migratory within NZ
Chrysococcyx lucidus	Shining cuckoo	Not Threatened	Diurnal, and nocturnal flights	Native forest and scrub where grey warbler occur	Migratory - international
Circus approximans	Swamp harrier	Not Threatened	Diurnal	Coastal fringe, estuaries, wetlands, pine forest, farmland and high-country, urban areas	Seasonal migration
Cygnus atratus	Black swan	Not Threatened	Diurnal	Lakes and larger constructed ponds, estuaries	Nomadic (finding more favourable habitat)
Cyanoramphus novaezelandiae	Red-crowned parakeet	At Risk-Relict	Diurnal	Offshore islands or pest-free mainland reserves	Seasonal migration
Egretta novaehollandiae	White-faced heron	Not Threatened	Diurnal	Rocky shores and estuary mudflats, shallow edges of lakes, farm ponds, damp pasture, sports fields, urban areas.	Nomadic (possible international vagrant)
Egretta sacra	Reef heron	Threatened-Nationally Endangered	Diurnal and nocturnal	Rocky shores and estuary mudflats	Nomadic (possible international vagrant)
Eudynamys taitensis	Long-tailed cuckoo	At Risk-Naturally Uncommon	Diurnal, and nocturnal flights	Only occurs where whitehead occurs; extensive native or exotic forest or scrub, farmlands, urban areas	Migratory - international
Eudyptula minor	Blue penguin	At Risk-Declining	Diurnal and nocturnal	Coastline and offshore islands	Not migratory
Falco novaeseelandiae	New Zealand falcon	Threatened-Nationally Vulnerable	Diurnal	Native podocarp and beech forest, tussocklands, roughly grazed hill country, pine forest and vineyards	Long-range dispersal
Gerygone igata	Grey warbler	Not Threatened	Diurnal	Woody vegetation in urban and rural areas	Seasonal migration
Haematopus finschi	Pied oystercatcher	At Risk-Declining	Diurnal and nocturnal	Riverbeds, farmland, high country grasslands, coastal areas adjacent to estuaries and lagoons	Migratory (including some international)

Species	Common Name	National Threat Classification	Trait with light (d/n/c)	habitat	Migratory pattern[13]
Haematopus unicolor	Variable oystercatcher	At Risk-Recovering	Diurnal and nocturnal	Sandy beaches, sand spits, dunes, banks, rocky shorelines, gravel beaches, inter-tidal mud-flats in estuaries, paddocks, and mown or grazed grassy areas or bare ground	Not migratory
Hemiphaga novaeseelandiae	Kererū	Not Threatened	Diurnal	Podocarp-broadleaf forest, beech forest, second growth native forest regenerating after logging, small forest remnants, and exotic plantations, farmland shelterbelts, urban parks, and rural and suburban gardens	Seasonal migration
Himantopus himantopus	Pied stilt	At Risk-Declining	Diurnal and nocturnal	wetlands from brackish estuaries and saltmarshes to freshwater lakes, swamps and braided rivers	Migratory (seasonally in NZ) (possible international vagrant)
Hirundo neoxena	Welcome swallow	Not threatened	Diurnal	close to wetlands or the coast and in most habitats other than dense forest or alpine areas	Migratory in NZ
Hydroprogne caspia	Caspian tern	Threatened-Nationally Vulnerable	Diurnal, and nocturnal flights	Sheltered bays and harbours, inland lakes, open coastal shellbanks, sandspits, and braided river beds	Nomadic in NZ
Larus dominicanus	Southern black-backed gull	Not Threatened	Diurnal	Estuaries and harbours, rocky and sandy shores, riverbeds; farmland, subalpine tussock land and herb fields	Not migratory (possible international vagrant)
Larus bulleri	Black-billed gull	Threatened-Nationally Critical	Diurnal	Inland rivers, coastal shell banks, sandspits, lake-side marinas, hydroelectric dams and ports	Migratory in NZ
Larus novaehollandiae	Red-billed gull	Threatened-Nationally Vulnerable	Diurnal	coastal areas, river mouths and sandy and rocky shores	Seasonal migration (breeding) (possible international vagrant)
Limosa lapponica	Eastern bar-tailed godwit	At Risk-Declining	Diurnal and nocturnal	Inter-tidal zone, harbours, estuaries and wet pasture	Migratory - international
Mohoua albicilla	Whitehead	Not Threatened	Diurnal	tall native forest, dense shrubland and mature pine plantations	Seasonal migration
Morus serrator	Australasian gannet	Not Threatened	Diurnal, and nocturnal flights	coastal rocks and islands,	Migratory (breeding)
Nestor meridionalis septentrionalis	North Island kaka	Threatened-Nationally Vulnerable	Diurnal	Native forests, offshore islands and urban parks	Seasonal migration

Species	Common Name	National Threat Classification	Trait with light (d/n/c)	habitat	Migratory pattern[13]
Ninox novaeseelandiae	Morepork	Not Threatened	Nocturnal	Native and exotic forests, open areas with patches of vegetation, sparsely-wooded farmland, and urban parks/ gardens	Not migratory
Onychoprion fuscatus	Sooty tern	At Risk-Naturally Uncommon	Diurnal and nocturnal	Atolls, sandbanks, rock stacks, offshore islands	Migratory - Kermadec Islands
Petroica longipes	North Island robin	Not Threatened	Diurnal	Mature forest, tall scrub, and exotic plantations	Not migratory
Petroica macrocephala	Tomtit	Not Threatened	Diurnal	Mature native forest types, including podocarp-broadleaf, beech, and manuka-kanuka forests, regenerating forests, exotic plantations, well-treed farmland, and suburban parks/ gardens	Not migratory
Petroica macrocephala toitoi	North Island tomtit	Not Threatened	Diurnal	Mature native forest types, including podocarp-broadleaf, beech, and manuka-kanuka forests, regenerating forests, exotic plantations, well-treed farmland, and suburban parks/ gardens	Not migratory
Phalacrocorax carbo	Black shag	At Risk-Naturally Uncommon	Diurnal	Coastal waters, estuaries, harbours, rivers, streams, lakes and ponds	Long distance dispersal (including international)
Phalacrocorax melanoleucos	Little shag	Not Threatened	Diurnal	Coastal and freshwater habitats that include lakes, rivers, ponds and streams	Seasonal migration
Phalacrocorax sulcirostris	Little black shag	At Risk-Naturally Uncommon	Diurnal	Harbours, lakes, braided rivers, muddy edges of inland/ coastal inlets, lakes and ponds, including sewerage ponds	Nomadic (possible international vagrant)
Phalacrocorax varius	Pied shag	Threatened-Nationally Vulnerable	Diurnal	Coastal marine waters, harbours, estuaries, freshwater lakes and ponds close to the coast	Long distance dispersal (possible international vagrant)
Platalea regia	Royal spoonbill	At Risk-Naturally Uncommon	Diurnal and nocturnal	Estuaries, rivers and harbours, reeds, low shrubs, steep rocky headlands,	Migratory in NZ (possible international vagrant)
Poliocephalus rufopectus	New Zealand dabchick	Threatened-Nationally Vulnerable	Diurnal, and nocturnal flights	Freshwater lakes and pools, sand-dune lakes and lagoons	Nomadic
Porphyrio melanotus	Pukeko	Not Threatened	Diurnal	Sheltered fresh or brackish water (e.g. vegetated swamps, streams or lagoons), especially adjacent to open grassy areas and pastures, near roadside, drainage ditches, margins of scrub or forested areas	Not migratory (possible international vagrant)

Species	Common Name	National Threat Classification	Trait with light (d/n/c)	habitat	Migratory pattern[13]
Porzana tabuensis	Spotless crake	At Risk-Relict	Diurnal	Freshwater wetlands, open mud near dense vegetation, dry island forests,	Not migratory (possible international vagrant)
Prosthemadera novaeseelandiae	Tui	Not Threatened	Diurnal	Native forest and scrub (sometimes in exotic forests), rural gardens, stands of flowering kowhai and gums, suburban parks and gardens	Seasonal migration
Puffinus gavia	Fluttering shearwater	At Risk-Relict	Diurnal and nocturnal	Offshore islands	Migratory - international
Puffinus griseus	Sooty shearwater	At Risk-Declining	Diurnal and nocturnal	Offshore islands	Migratory - international
Puffinus huttoni	Hutton's shearwater	At Risk-Declining	Diurnal and nocturnal	Forested streams, coastal areas and steep tussock-covered slopes	Migratory - international
Rhipidura fuliginosa	New Zealand fantail	Not Threatened	Diurnal	Native and exotic forest, shrubland, farm shelterbelts, orchards, and well-treed suburban parks and gardens.	Seasonal migriation
Sterna striata	White-fronted tern	At Risk-Declining	Diurnal	Coastal areas, small islands and rivers	Seasonal migration (international long distance dispersal)
Stictocarbo punctatus	Spotted shag	Not Threatened	Diurnal	Coastal waters out to 16 km, entering inlets and estuaries	Not migratory
Tadorna variegata	Paradise shelduck	Not Threatened	Diurnal	Pastoral landscape, river flats in mountain areas, heads of protected bays or fiords, the shorelines of all large lakes and hydro-dams, and recreational grasslands and parks within urban areas.	Not migratory (long-distance dispersal)
Todiramphus sanctus	Sacred kingfisher	Not Threatened	Diurnal	Farmland with trees, and river banks	Seasonal migration (breeding)
Vanellus miles	Spur-winged plover	Not Threatened	Diurnal	Areas with low vegetation, near water margins of marine and terrestrial wetlands, riverbeds and lake shores, estuaries, beaches, farm pastures, grassland in urban areas, parks, road verges	Migratory (possible international vagrant)
Zosterops lateralis	Slivereye	Not Threatened	Diurnal	Urban areas, farmlands, orchards, native and exotic forests, scrublands and scrubby edges of wetlands	Seasonal migration (possible international vagrant)

Table 2. Mammal species reported in Lower Hutt District

Species	Common Name	National Threat Classification	Trait with light (d/n/c)	habitat	Migratory status
Arctocephalus forsteri	New Zealand fur seal	Not Threatened	Diurnal and nocturnal	Coastal and foreshore	Not migratory
Hydrurga leptonyx	Leopard Seal	At Risk – Naturally Uncommon	Diurnal and nocturnal	Coastal and foreshore (rare in NZ)	Migratory
Chalinolobus tuberculatus	Long-tailed bat	Threatened-Nationally Vulnerable	Nocturnal	Forest and lines of trees	Migratory

Table 3. Lizard species reported in Lower Hutt District

Species	Common Name	National Threat Classification	Trait with light (d/n/c)	habitat
Dactylocnemis pacificus	Pacific gecko	At Risk-Relict	Nocturnal; by day very secretive but may sun-bask at entrance to retreat	Forest and scrubland trees, creviced clay banks and rock bluffs, rock outcrops, and associated scrubby vegetation including flax, coastlines among driftwood, rocks and scrub, hill country and lowland areas (mostly recorded in Hutt Valley)
Mokopirirakau granulatus	Forest gecko	At Risk-Declining	Largely nocturnal, and at least some North Island populations also diurnal	Forest and shrublands, from the coast upwards to the tree line
Mokopirirakau "southern North Island"	Southern North Island forest gecko	At Risk-Declining	Largely nocturnal, sun-basks near retreat or among vegetation	Forest and shrublands
Naultinus punctatus	Wellington green gecko	At Risk-Declining	Diurnal, sun-basks among foliage	Forest and scrub, including manuka/kanuka shrubland, and lowland areas
Oligosoma aeneum	Copper skink	Not Threatened	Mostly diurnal	Forest and open or shaded areas with adequate groundcover such as logs, rocks or long grass or deep leaf litter, urban areas: compost heaps, rock gardens
Oligosoma newmani	Speckled skink	At Risk-Declining	Diurnal	Open forest, scrubby areas, tussock country, rough pasture with debris, rock piles and boulder beaches
Oligosoma lineoocellatum	Spotted skink	At Risk-Relict	Diurnal	Duneland, shrubland, river terrace, outcropping rock, cliff edge, tussock grassland and rocky habitats
Oligosoma ornatum	Ornate skink	At Risk-Declining	Very secretive, can become active at any time but mostly at dawn and dusk	Forest or open areas with deep leaf litter, or stable cover such as deep rock piles
Oligosoma polychroma	Common skink	Not Threatened	Diurnal	Sand dunes, grasslands, herbfields, wetlands, rocky areas including rock piles and scree, and scrub
Oligosoma zelandicum	Brown skink	At Risk-Declining	Diurnal	Densely vegetated and typically damp habitats in lowland areas, including forest, scrub, farmland and coastlines, including among pohuehue on boulder banks
Sphenodon punctatus	Tuatara	At Risk-Relict	Nocturnal, but emerges by day to bask	Coastal forest and clearings, especially where the ground has been tunnelled by nesting seabirds
Woodworthia maculata	Common gecko	Not Threatened	Largely nocturnal, but sun-basks at entrance to retreat	Forest trees, Creviced rock outcrops, bluffs and rock tumbles, including associated scrubby vegetation, in open or scrubby areas, coastlines among driftwood and boulders banks

Table 4. Invertebrate taxa reported in Lower Hutt District

Insect order	Number of taxa	Commonly known members
Archaeognatha	1	Bristletails
Blattodea	15	Cockroaches and termites
Coleoptera	200	Beetles
Dermaptera	3	Earwigs
Diptera	160	Trueflies such as horse-flies, crane flies and hoverflies
Ephemeroptera	10	Mayflies
Hemiptera	90	Cicadas, aphids, plant hoppers, leaf hoppers, bed bugs and shield bugs
Hymenoptera	77	Sawflies, wasps, bees, and ants
Lepidoptera	297	Butterflies and moths
Mantodea	2	Mantises
Megaloptera	1	Dobsonflies
Neuroptera	3	Lacewings, mantidflies and antlions
Odonata	8	Dragonflies and damselflies
Orthoptera	26	Grasshoppers, locusts and crickets
Phasmida	11	Stick insects, stick-bugs, walking sticks, or bug sticks
Plecoptera	5	Stoneflies
Psocodea	4	Bark lice, book lice and true lice
Siphonaptera	2	Flea
Thysanoptera	2	Thrips
Trichoptera	17	Caddisflies
Zygentoma	2	Silverfish or fishmoths, and the firebrats
Unclassified winged insect	1	

Table 5. Freshwater fish species reported in Lower Hutt District

Species	Common Name	National Threat Classification	Trait with light (d/n/c)	habitat	Migratory pattern
Anguilla dieffenbachii	Longfin eel	At risk: Declining	Predominantly nocturnal but may active during the daytime as well	Stream/ lake	Catadromous
Anguilla australis	Shortfin eel	Not threatened	Predominantly nocturnal but may active during the daytime as well	Stream/ wetland	Catadromous
Galaxias postvectis	Shortjaw kokopu	Threatened: Nationally vulnerable	Nocturnal but may be active at dawn and dusk	Stream	Non migratory
Galaxias fasciatus	Banded kokopu	Not threatened	Nocturnal	Stream/ lake	Amphidromous
Galaxias argenteus	Giant kokopu	At risk: Declining	Nocturnal	Stream/ lake	Amphidromous
Galaxias brevipinnis	Koaro	At risk: Declining	Nocturnal	Stream/ lake	Amphidromous
Galaxias divergens	Dwarf galaxias	At risk: Declining	Nocturnal	Stream	Non migratory
Retropinna retropinna	Common smelt	Not threatened	Nocturnal	Stream/ lake	Anadromous
Galaxias maculatus	Inanga	At risk: Declining	Nocturnal and darting at daytimes	Stream/ lake	Catadromous
Gobiomorphus cotidianus	Common bully	Not threatened	Nocturnal and darting at daytimes	Stream/ lake	Amphidromous
Gobiomorphus gobioides	Giant bully	At risk: Naturally uncommon	Nocturnal	Stream	Amphidromous
Gobiomorphus huttoni	Redfin bully	Not threatened	Nocturnal	Stream	Amphidromous
Gobiomorphus basalis	Cran's bully	Not threatened	Nocturnal	Stream	Non migratory
Gobiomorphus hubbsi	Bluegill bully	At risk: Declining	Nocturnal	Stream	Amphidromous
Geotria australis	Lamprey	Threatened: Nationally vulnerable	Nocturnal	Stream	Anadromous
Aldrichetta forsteri	Yelloweyed mullet	Not threatened	Nocturnal	Lowland streams	Non migratory
Grahamina nigripenne	Estuarine triplefin	Not threatened	Nocturnal	Estuaries	Non migratory

APPENDIX

B

BEST PRACTICE LIGHTING DESIGN

Appendix A from DEE 2020 report – reproduced in full.

Natural darkness has conservation value in the same way as clean water, air and soil and should be protected through good quality lighting design.

Simple management principles can be used to reduce light pollution, including:

1. **Start with natural darkness and only add light for specific purposes.**
2. **Use adaptive light controls to manage light timing, intensity and colour.**
3. **Light only the object or area intended – keep lights close to the ground, directed and shielded to avoid light spill.**
4. **Use the lowest intensity lighting appropriate for the task.**
5. **Use non-reflective, dark-coloured surfaces.**
6. **Use lights with reduced or filtered blue, violet and ultra-violet wavelengths.**

The application of best practice lighting design for all outdoor lighting is intended to reduce sky glow and minimise the effects of artificial light on wildlife.

Lighting Objectives

At the outset of a lighting design process, the purpose of artificial lighting should be clearly stated and consideration should be given as to whether it is required at all.

Exterior lighting for public, commercial or industrial applications is typically designed to provide a safe working environment. It may also be required to provide for human amenity or commerce. Conversely, areas of darkness, seasonal management of artificial light, or minimised sky glow may be necessary for wildlife protection, astronomy or dark sky tourism.

Lighting objectives will need to consider the regulatory requirements and Australian standards relevant to the activity, location and wildlife present.

Objectives should be described in terms of specific locations and times for which artificial light is necessary. Consideration should be given to whether colour differentiation is required and if some areas should remain dark – either to contrast with lit areas or to avoid light spill. Where relevant, wildlife requirements should form part of the lighting objectives.

A lighting installation will be deemed a success if it meets the lighting objectives (including wildlife needs) and areas of interest can be seen by humans clearly, easily, safely and without discomfort.

The following provides general principles for lighting that will benefit the environment, local wildlife and reduce energy costs.

Principles of Best Practice Lighting Design

Good lighting design incorporates the following design principles. They are applicable everywhere, especially in the vicinity of wildlife.

1. Start with natural darkness

The starting point for all lighting designs should be natural darkness (Figure 1). Artificial light should only be added for specific and defined purposes, and only in the required location and for the specified duration of human use. Designers should consider an upper limit on the amount of artificial light and only install the amount needed to meet the lighting objectives.

In a regional planning context, consideration should be given to designating 'dark places' where activities that involve outdoor artificial light are prohibited under local planning schemes.

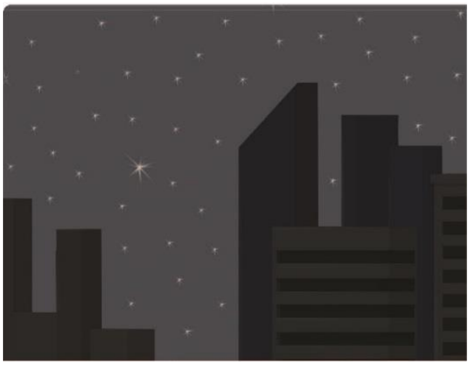

Figure 1 Start with natural darkness.

2. Use adaptive controls

Recent advances in smart control technology provide a range of options for better controlled and targeted artificial light management (Figure 2). For example, traditional industrial lighting should remain illuminated all night because the High-Pressure Sodium, metal halide, and fluorescent lights have a long warm up and cool down period. This could jeopardise operator safety in the event of an emergency. With the introduction of smart controlled LED lights, plant lighting can be switched on and off instantly and activated only when needed, for example, when an operator is physically present within the site.

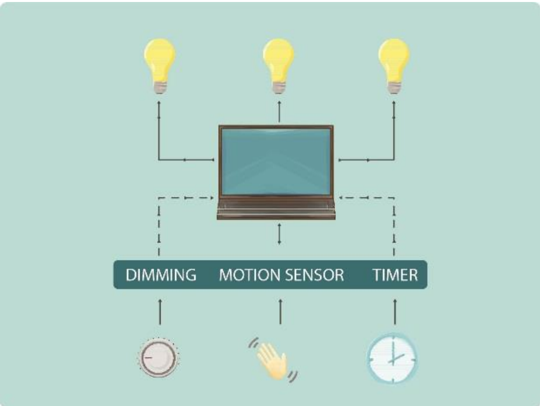

Figure 2 Use adaptive controls to manage light timing, intensity and colour.

Smart controls and LED technology allow for:

- remotely managing lights (computer controls)
- instant on and off switching of lights
- control of light colour (emerging technology)
- dimming, timers, flashing rate, motion sensors well defined directivity of light.

Adaptive controls should maximise the use of latest lighting technology to minimise unnecessary light output and energy consumption.

3. Light only the intended object or area - keep lights close to the ground, directed and shielded

Light spill is light that falls outside the area intended to be lit. Light that spills above the horizontal plane contributes directly to artificial sky glow while light that spills into adjacent areas on the ground (also known as light trespass) can be disruptive to wildlife in adjacent areas. All light fittings should be located, directed or shielded to avoid lighting anything but the target object or area (Figure 3). Existing lights can be modified by installing a shield.

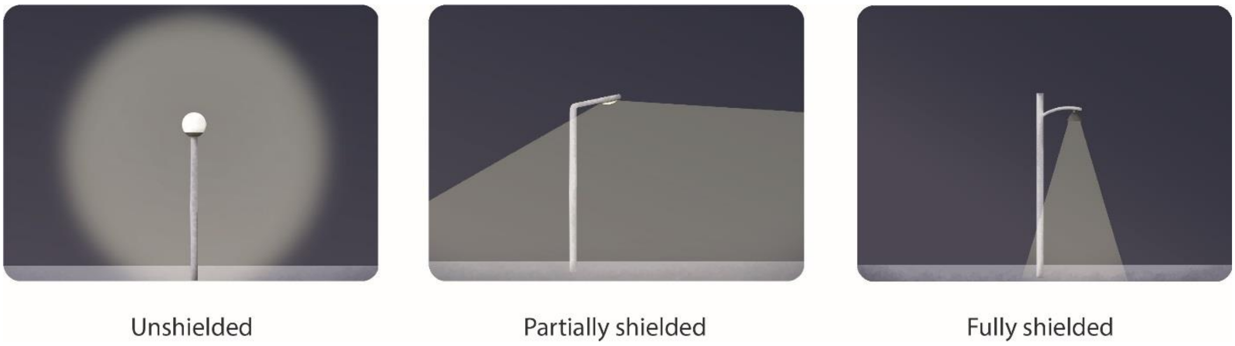

Figure 3 Lights should be shielded to avoid lighting anything but the target area or object. Figure adapted from Witherington and Martin (2003)[3].

Lower height lighting that is directional and shielded can be extremely effective. Light fixtures should be located as close to the ground as possible and shielded to reduce sky glow Figure 4.

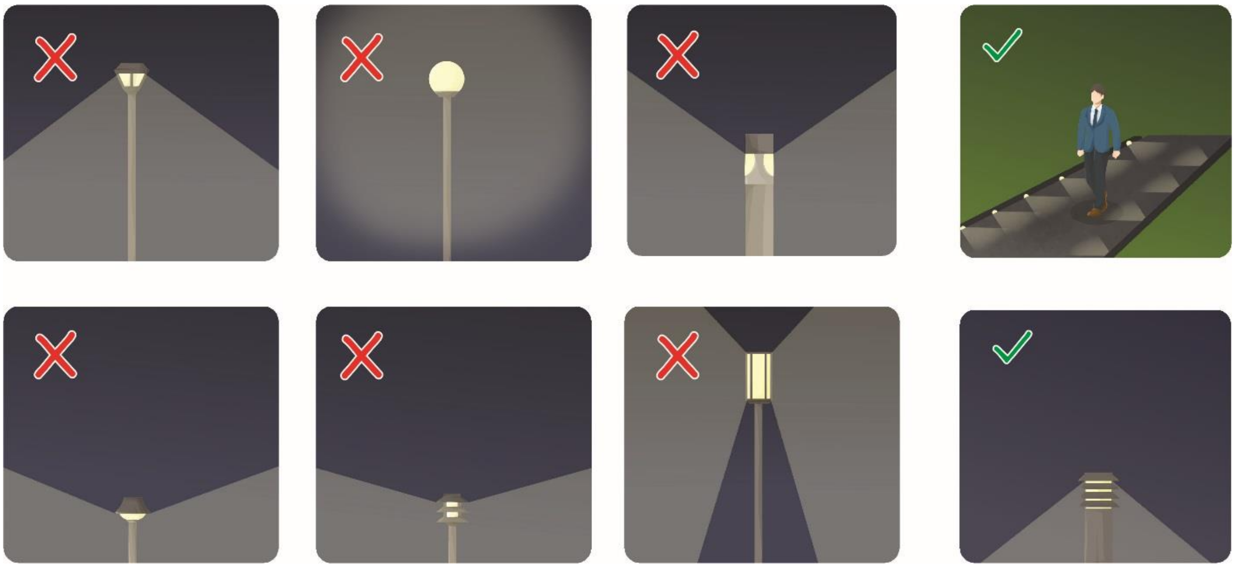

Figure 4 Walkway lighting should be mounted as low as possible and shielded. Figure adapted from Witherington and Martin (2003)[3].

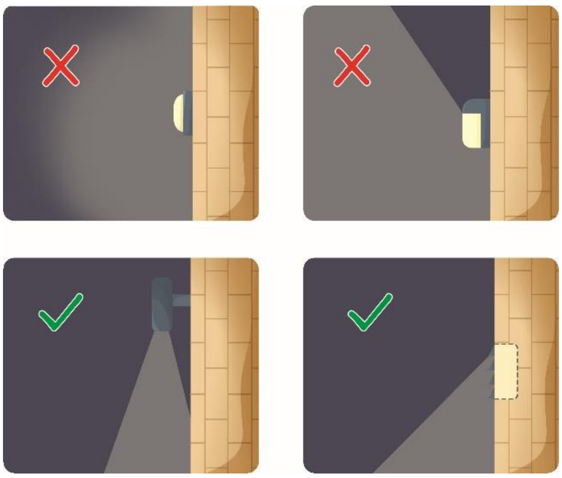

Figure 5. Lighting should be directed to ensure only the intended area is lit. Figure adapted from Witherington and Martin (2003)[3].

Artificial light can be prevented from shining above the horizontal plane by ensuring the luminaire is mounted horizontally relative to the ground and not at an angle, or mounted on a building so that the structure prevents the light shining above the horizontal plane, for example recess a light into an overhanging roof eave. When determining angle of the mounting, consideration should be given to the reflective properties of the receiving environment.

If an unshielded fitting is to be used, consideration should be given to the direction of the light and the need for some form of permanent physical opaque barrier that will provide the shielding requirement. This can be a cover or part of a building (Figure 5). Care should be taken to also shield adjacent surfaces, if they are lightly coloured, to prevent excessive reflected light from adding to sky glow.

Consideration should also be given to blocking light spill from internal light sources. This should include block-out blinds or shutters for transparent portions of a building, including sky lights, and use of glass in windows and balconies with reduced visible light transmittance values.

4. Use appropriate lighting

Lighting intensity should be appropriate for the activity. Starting from a base of no lights, use only the minimum number and intensity of lights needed to provide safe and secure illumination for the area at the time required to meet the lighting objectives. The minimum amount of light needed to illuminate an object or area should be assessed during the early design stages and only that amount of light installed. For example, Figure 5 provides options from best to worst for lighting for a parking lot.

Figure 5 Lighting options for a parking area. Figure adapted from Witherington and Martin (2003)[3].

Off-the-shelf lighting design models

Use of computer design engineering packages that do not include wildlife needs and only recommend a standard lighting design for general application should be avoided or modified to suit the specific project objectives, location and risk factors.

Consider the intensity of light produced rather than the energy required to make it

Improvements in technology mean that new bulb types produce significantly greater amount of light per unit of energy. For example, LED lights produce between two and five times the amount of light as incandescent bulbs. The amount of light produced (lumen), rather than the amount of energy used (watt) is the most important consideration in ensuring that an area is not over lit.

Consider re-evaluating security systems and using motion sensor lighting

Technological advances mean that techniques such as computer managed infra-red tracking of intruders in security zones is likely to result in better detection rates than a human observer monitoring an illuminated zone.

Use low glare lighting

High quality, low glare lighting should always be a strong consideration regardless of how the project is to be designed. Low glare lighting enhances visibility for the user at night, reduces eye fatigue, improves night vision and delivers light where it is needed.

5. Use non-reflective, dark coloured surfaces

Light reflected from highly polished, shiny or light-coloured surfaces such as white painted infrastructure, polished marble or white sand can contribute to sky glow. For example, alternatives to painting storage tanks with white paint to reduce internal heating should be explored during front-end engineering design. In considering surface reflectance, the need to view the surface should be taken into consideration as darker surfaces will require more light to be visible. The colour of paint or material selected should be included in the Artificial Light Management Plan.

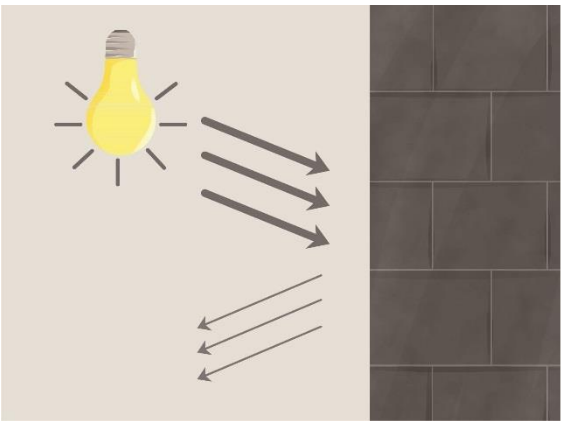

Figure 6 Use non-reflective dark coloured surfaces.

6. Use lights with reduced or filtered out blue, violet and ultraviolet wavelengths

Short wavelength light (blue) scatters more readily in the atmosphere and therefore contributes more to sky glow than longer wavelength light. Further, most wildlife are sensitive to short wavelength (blue/violet) light (for detailed discussion see What is Light and how do Wildlife Perceive it?). As a general rule, only lights with little or no short wavelength (400 – 500 nm) violet or blue light should be used to avoid unintended effects. Where wildlife are sensitive to longer wavelength light (e.g. some bird species), consideration should be given to wavelength selection on a case by case basis.

When determining the appropriate wavelength of light to be used, all lighting objectives should be taken into account. If good colour rendition is required for human use, then other mitigation measures such as tight control of light spill, use of head torches, or timers or motion sensors to control lights should be implemented.

It is not possible to tell how much blue light is emitted from an artificial light source by the colour of light it produces (see Light Emitting Diodes). LEDs of all colours, particularly white, can emit a high amount of blue light and the Colour Correlated Temperature (CCT) only provides a proxy for the blue light content of a light source. Consideration should be given to the spectral characteristics (spectral power distribution curve) of the lighting to ensure short wavelength (400 – 500 nm) light is minimised.

About Cardno

Cardno is a professional infrastructure and environmental services company, with expertise in the development and improvement of physical and social infrastructure for communities around the world. Cardno's team includes leading professionals who plan, design, manage and deliver sustainable projects and community programs. Cardno is an international company listed on the Australian Securities Exchange [ASX:CDD].

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