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ECA
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INSIDE THIS ISSUE!

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Front Cover Photo: *Brush-tailed Rock Wallaby*

Courtesy of Steve Sass

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ECA COUNCIL MEETINGS

The ECA Council meet every three months to discuss and deal with any current business of the association. Any member who wishes to view the minutes from any of the ECA council meetings may do so by contacting the Administration Assistant Amy Rowles admin@ecansw.org.au

Message from the President

Dear Members,

Welcome to this larger issue of *Consulting Ecology*, a special edition to compensate for the cancellation of ECA NSW annual conference and workshops this year due to social-distancing, crowd-size and travel restrictions imposed by the COVID-19 pandemic. On behalf of the ECA NSW Council, I hope that you are all well and that ecological consulting activities will return to normal with future easing of COVID-19 restrictions.

While many ecological consultants perform Five-part Tests of Significance and Biodiversity Assessment Method (BAM) assessments, we must not forget that there are other forms of ecological consultancy. This edition of *Consulting Ecology* examines more closely a few of the ecological issues that we investigate collectively as ecological consultants. Therefore, I take this opportunity to thank authors and contributors who have contributed to this edition, many of whom have demonstrated the breadth of ecological consultancy in NSW. I also thank Brian Wilson and Amy Rowles for making sense of all the material received and assembling it into an informative and interesting format. I hope that this edition inspires the broader membership to rise to the challenge of providing material for future editions. If we can do it this time around, we can do it again!

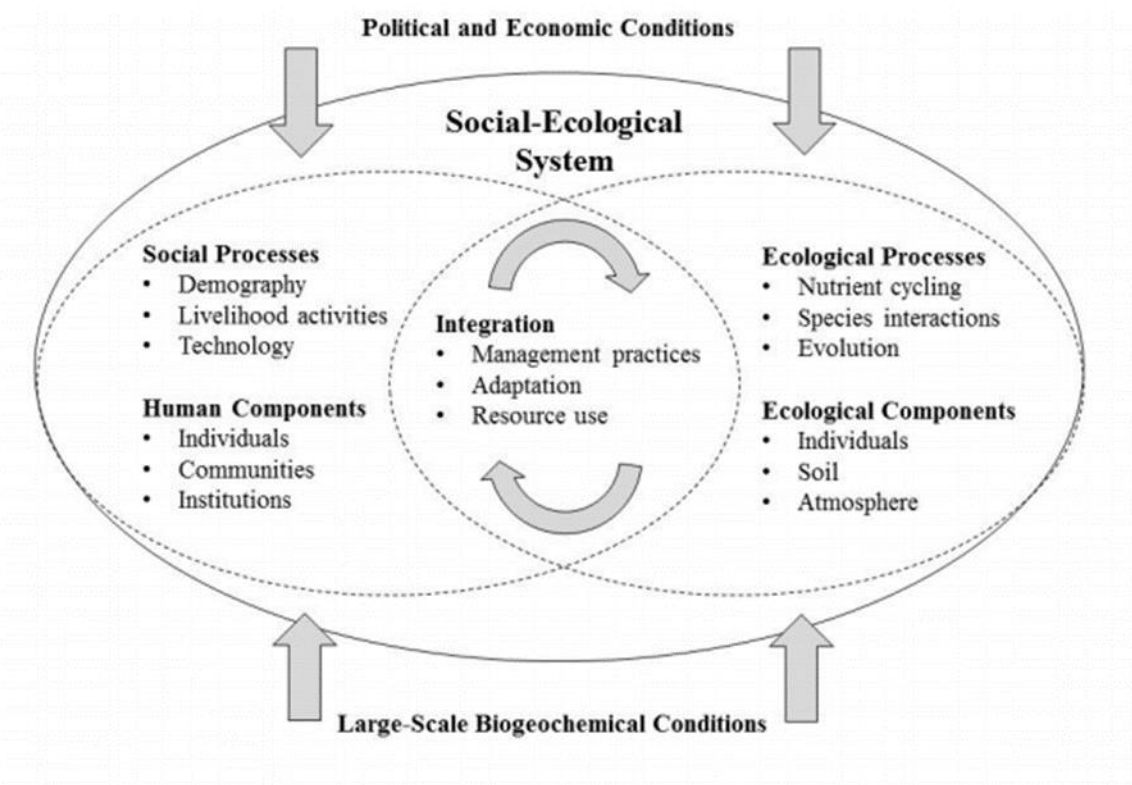
What is an ecological consultant?

The independent panel of the ECA NSW's Certified Practising Ecological Consultants (CPEC) Scheme had some difficulty recently in addressing this question when assessing CPEC applications. After some discussion they finally arrived at a decision, but reached out to others to help them to better understand the broad umbrella of services that an ecological consultant may provide clients. I offer my own thoughts on this topic after discussions with members of the CPEC Panel, all of whom I thank immensely for their reviews of an earlier draft.

In theory, ecological consulting involves working for a client to apply ecological science to solve problems in social–ecological systems (Redman *et al*. 2004) and to make those systems more resilient (Walker *et al*. 2004), where:

a social-ecological system comprises ecological and social processes and components which are integrated through management practices, adaptation and resource use (Virapongse *et al.* 2016) (Figure 1). Integration is influenced by broad-scale forces such as political, economic and global biogeochemical (nutrient and water) conditions; and *resilience* is the capacity of an ecosystem to adapt to disturbances and changes in the environment (Berkes *et al*. 2003; Young *et al*. 2006).

Figure 1 Structure of a Social Ecological System (from Virapongse *et al*. 2016)



In practice, this translates to most ecological consultants (especially ECA NSW members) assessing the impacts of proposed developments and activities on the status of flora and fauna and their habitats, and recommending how to avoid or minimise those impacts. The economic demand and capacity, political ideologies of governments, political lobbying and legislation are the *political and economic conditions* that drive our social-ecological system. The *human components* comprise governments who set policies, legislation and regulations, determine the zoning of landscapes, and are involved in the application assessment process; the proponent of the development; the environmental impact assessors; and the individuals and communities who comment on the proposals (the lobbyists), as well as those who occupy and manage the land if the development is approved. The *social processes* involve human population growth and distributions, commercial and employment opportunities, and the stages and procedures associated with a development, i.e. all those anthropogenic processes that drive the need for, and influence the nature of, a proposed development. The *ecological components* include the flora and fauna (especially threatened biota), their population sizes and distributions, their habitats and their broader environment that have the potential to be impacted by the proposed development or activity. A study of the *ecological processes* takes into account, the structures and species relationships within ecological communities, the dependence on, and the availability of, resources (e.g. food plants, soil type and nutrients, rainfall) and includes the recognition and assessment of listed Key Threatening Processes. *Large-scale biogeochemical conditions* take into account the availability and condition of resources for flora and fauna as a result of broader-scale processes such as global warming, extreme weather events, and broadscale clearing, fragmentation and degradation (e.g. pollution, impacts of invasive species) of the wider landscape or waterscape. All these factors are taken into account by the ecological consultant (i.e. *integration*) when assessing current environmental management practices, recommending to a broad audience the measures for avoiding or significantly reducing biodiversity impacts of the proposed development or activity, and monitoring their effectiveness.

But not all applied ecologists are involved in the assessment of development or activity applications or, if they are, they provide a specialised and skilled service that may be only one small part of the assessment. They may specialise in particular tasks such as:

- developing threat abatement plans, conducting broadscale reviews and analyses of specific ecological conditions in the natural environment (e.g. broadscale mapping of vegetation communities, landscape identification of biodiversity hotspots or important habitats for specific taxa, or reviewing the effectiveness of species recovery plans); or

- provision and analysis of data on specific taxa (e.g. bats, shorebirds or orchids); or

- specialist field skills in ecology (e.g. environmental DNA sampling; ecological surveys using drones and the subsequent analysis of data; or nest box design, installation, research and monitoring).

Yet, they are still ecological consultants because they are paid by clients for their services, they are not salaried employees of those clients, and they fit easily into the *human components* category of a social-ecological system. Their main roles as members of this category are the collection and analysis of specific ecological data about *ecological components* and *ecological processes*. They also contribute directly or indirectly to the *integration* process (usually by providing recommendations for environmental management). I consider it analogous with the medical profession: medical specialists (e.g. oncologists, obstetricians, surgeons) are paid by a patient for specific medical advice and treatment, but they are still part of the broader medical profession. Without that specialist medical expertise, a lot of serious medical problems would be undiagnosed and untreated. Similarly, specialist ecologists are paid by clients to provide expertise in a very narrow field of ecology, but in a highly-informed way, and they are still part of the ecological consulting industry. Without that specialist ecological expertise, there is a risk of critical ecological factors being undetected or unrecognised, and consequently left unmanaged.

A good ecologist does not necessarily mean a good ecological consultant. They also need to be both ethical and skilled at running or being part of a business. In an ecosystem, relationships between organisms (including humans), and with their physical environment, are complex and are often difficult to model and predict, especially within the time-frame and resource availability of most consultancy projects. Consequently, the precautionary principle always applies when promoting ecologically sustainable development. An ecological consultant needs to communicate that principle to clients in the context of ecological science, legislative and associated government administrative frameworks, and the aspirations of the client. Not all ecological scientists have this contextual capacity or those broad communication skills.

Therefore, an ecological consultant must be good at marketing their business, writing fee proposals, doing background research online, interviewing key informants, meeting with communities, conducting field surveys or site inspections, data management and collection, writing reports and giving presentations, efficient and ethical at advising and billing clients, multi-tasking, and managing their time efficiently. They must also have the necessary skills, experience, qualifications, knowledge (e.g. scientific, technical, legislative and regulatory), licences and business insurance that are appropriate for their specific involvement in a project. And this brings me to the topic of professional development – the need to keep up with the latest scientific, legislative and business developments that are relevant to their field of work. This means attending appropriate conferences and workshops, reading peer-reviewed journals and other relevant publications, perhaps writing a review paper for *Consulting Ecology* or another journal and, if the opportunity arises, conducting and publishing original ecological research.

There is always a degree of uncertainty in predicting ecological outcomes because of the complexity and variability (temporal, geographical and structural) of ecosystems and their processes, many of which are not well understood. Therefore, ecological outcomes can only be predicted in terms of probability rather than certainty. A good practising ecological consultant must be competent and trustworthy at assessing an ecological problem, and be able to recognise and explain the limitations and uncertainties of the data and conclusions. They must be able to defend their work in court, know the limits to their knowledge and expertise, and be honest with themselves and others in the conduct of their work. Above all, good consultants pass on work that is outside their areas of expertise to others who do have the expertise, rather than attempting to do it themselves. Collectively, these attributes require both professional integrity and adequate professional experience.

Of course, you all know this, but I thought it was worth emphasising in the context of the CPEC Scheme. If you have all of these attributes, you may like to apply to become a CPEC, if not one already. It is a form of peer-recognition that you are a good ecological consultant, which will ultimately make you more marketable as a stand-alone consultant or company employee. A company that employs CPECs is also likely to be more attractive to potential clients.

Now that I have that off my chest, all that is left for me to do is to invite you to sit back and enjoy this edition of *Consulting Ecology*. Enjoy!

Dr Stephen Ambrose
ECA NSW President
October 2020

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WHAT BIRD ARE YOU?

Try this for a bit of fun. It is American birds, but might inspire someone to create an Australian equivalent.

https://cornelllabpgstore.com/what-bird-are-you-most-like-all-outcomes/

Amy

Result: You Are an American Kestrel!

EUROKY

Euroky***: ability of an organism to adapt to changes in the environment***

If you have any interesting observations or useful hints and information that you would like to share in the euroky column, please forward them to the newsletter editor or administration assistant to be included in the next edition.

SMALL AREA STREAMLINED ASSESSMENT AND RECENTLY/ SEVERELY BURNT GUIDELINES

Andrew Lothian
Biodiversity Monitoring Services

Under the guidelines for assessing severely burnt areas we have to assume all species credit species are present unless an expert report says otherwise. Under the small area streamlined assessment we assume species credit species are not present unless seen during plot or other site visits (except if it is an SAII species). I asked BAM Support to clarify which assessment pathway takes precedence over the other in terms of species impacted by fire. The following was the response:

"For small area assessments using the Guideline for applying the BAM at a severely burnt site (BDARs/ BCARs), we recommend that you identify any species credit species at risk of SAII and assume presence (unless you obtain an expert report or have evidence to support why they should be determined absent, as per the guideline). In this case, you would need to address the criteria detailed in the BAM, section 10.2.3.

For the remaining species credit species, you may assume they are not present unless seen during plot or other site visits. You will however, need to undertake a site visit including the burnt area, to justify this (this is relevant if you are using a surrogate site to determine the vegetation integrity)."

I have asked whether the list of SAII species will be updated in response to habitat loss during the recent fires and, as yet, have not received a response.

PHOTO COMPETITION

Congratulations! to ***Steve Sass*** for winning the last photo competition with his photograph featured on the front cover of *Brush-tailed Rock Wallabies.*

Thank you to everyone who entered our photo competition. As we received so many entries, we have retained a random selection for the next competition. All entries for this competition have been included in the ECA Photo Gallery on the back cover and center pages.

Email your favourite flora or fauna photo to admin@ecansw.org.au to enter a competition and have your photo on the cover of the next ECA newsletter. Win your choice of one year free membership or free entry into the next ECA annual conference. The winner will be selected by the ECA council. Runners up will be printed in the photo gallery. Please ensure that your photo is clear with a high resolution.

Photos entered in the competition may also be used on the ECA website

BEST WISHES TO CHANTELLE DOYLE AND MARK RAPLEY

Stephen Ambrose

ECA President

On Saturday, 15 August 2020 former ECA NSW Councillor and student grant recipient, Chantelle Doyle, was attacked by a Great White Shark at Port Macquarie while she was surfing. Chantelle's partner, Mark Rapley, fended off the shark and, with the help of others, ferried Chantelle ashore and applied emergency first-aid until the arrival of the emergency rescue services.

After the rescue, Chantelle was taken to Port Macquarie Hospital and then transferred to John Hunter Hospital in Newcastle for surgery. While Chantelle survived the attack, she acquired significant injuries to her right leg which necessitated extensive surgery.

Chantelle has been an active member of the ECA NSW. She is an enthusiastic conservationist, a competent researcher and excels in educating the public about conservation and plant ecology. Chantelle is currently studying towards a PhD at the University of NSW, investigating the best methods for translocating the critically-endangered *Hibbertia spanantha*.

Typically, Chantelle and Mark have used this experience to educate people about sharks and their conservation importance. They have launched a crowdfunding campaign for the Australian Marine Conservation Society, which relies on science and conservation to promote ocean health. You can donate to this campaign via the following link: https://give.everydayhero.com/au/shark

Chantelle's friends and colleagues know her as a friendly, energetic and all-round nice person, whom is also a devoted mother. Therefore, I am sure that you will join me in wishing Chantelle, Mark and their extended families, the very best over the coming months of recovery and rehabilitation. I hope you will donate to their worthy crowdfunding campaign too.

GET AN E-BIKE

Michael Murray

Forest Fauna Surveys Pty Ltd

Hi ECA, just thought I would share my experience with having an e-bike to assist with fieldwork. Wait, this article should be about ecological consultancy I hear you exclaim! Discussing an e-bike is more befitting of a mountain bike magazine. But please read on, the dots all join later in the piece.

As you are all aware, working in the bush, often remotely, sometimes presents access issues. Travelling down narrow overgrown and rutted tracks is tough on vehicles, and during or after recent rainfall increases the risk of getting bogged. Whilst there is a myriad of recovery equipment to add to the vehicle, it adds weight and cost. Recovery of vehicles is also with risk, with plenty of YouTube videos of what can go wrong. While walking is the easiest and probably most peaceful way to access remote sites with difficult access, it can add substantial time to your day.

Therefore, I contemplated whether there is a better and easier way to access remote sites without the angst of getting stuck, damaging a big heavy 4WD or the bush. I looked into a number of solutions, and recently purchased a dual suspension e-mtb (electric mountain bike). The other option was a e-motorbike, particularly a brand from those clever Kiwis called Ubco (www.ubcobikes.com), but there are a few others out there. However, motorbikes require a separate licence, you have to do a course, L and P licencing and annual registration / insurance. Also, there is no exercise, just sitting.

Having an e-mtb does not require any licencing and annual taxes, just the one-off purchase and regular servicing. How they work is when you pedal, you have assistance from the battery, when you stop pedalling, no assistance. When you come to a steep hill, just increase the power setting, easy. If you want, you can turn off the power and just ride like a normal pushbike. I guess the million-dollar question is how much is an e-bike? Well, it varies from less than $2,000 all the way to $20,000 (yes, count the zeros). The cheaper ones don't take much of a hiding in the bush, but are good for around town. I reckon from $4,000 upwards the quality of the bikes is improved. Still cheaper than a bull bar and winch on a 4WD.

The dual suspension makes travelling over rough tracks more comfortable. The battery power makes it easy to climb steep hills, or just any hill! Fieldwork has become fun again, I can get to sites much quicker than in a vehicle, encounter and hear many fauna species that would normally be missed while cocooned in a car. I am not bounced around as much compared with being in a car crawling up steep hills in low range, and conversely, going back down that steep hill is a hoot.

So, sounds good so far, but are there any drawbacks to having another piece of equipment to bundle in the car? E-bikes are heavy, about 25 kilograms for my bike, which requires a different carrier to the one I previously had. I came across a bike carrier (www.isi-carriers.com) which attaches to the hitch of your towbar, is perfect for 4WD's as it sits above the hitch giving great ground clearance so you don't bottom out and damage the carrier and bike. It is so easy to install and remove the bike. There are a number of comparable carriers out there (Thule, Yakima) with similar products; I bought from ISI carriers because it is a good Aussie company with a solid reputation and good after-sales support.

Because my bike has a removable battery, the

manufacturer recommends removing the battery during transportation. This is fine because the battery is very easy to remove. If travelling any distance between sites, you can top up the battery while driving. So far, I have travelled up to 60 kms in the bush on a single charge, so the e-bike will easily see through an entire day without the battery going completely flat. If this occurs, it is still easy to pedal without the assistance of the battery.

The modern mountain bikes are designed for long suspension travel, 130 mm+ if you really want to delve into it. This results in a frame with a small triangle, which makes carrying larger water bottles problematic. You can always use camel back water carriers, but having ridden many long-distance bicycle trips, I don't enjoy having anything on my back whilst cycling. Panniers are the way to go, but a dual-suspension bike presents problems. One option is a hard-tail style mountain bike, which has a solid rear frame designed to attach pannier racks. Hard-tail bikes don't have rear suspension, so tend to ride harder. Some bike riders claim they feel more fatigued at the end of the day, but this is probably a personal perspective. It's comparable to travelling in a Landcruiser rather than a HiLux!

However, there are several new styles of rack that enable front and rear panniers to be fitted to dual suspension bikes (www.topeak.com) but, again, there are several other carriers out there. So, my bike has racks with panniers which I can load up with gear (field cameras, bat detectors, binoculars, pump, bike spares, water, food) and then I am off for the day. I have looked into getting a surfboard carrier for bicycles so that a harp trap can be carried on the bike. I have also attached some brackets to the front handlebars to fix a light and gps to travel around at night doing spotlight searches and inspecting owl trees. Use of an e-bike during nocturnal work is great; travelling silently through the bush I have heard birds and gliders calling that I would have missed being in a noisy car.

So, has my e-bike changed the way I do field work? Well, I am much fitter, I don't have as sore a lower back from bouncing around in a car seat all day, my hit rate with reptiles and some cryptic birds has improved significantly, I am having a lot more fun getting to a site, I don't get bogged any more, and I don't have a dirty car to clean when I get home! I also rarely use my car at home these days, even a trip to Bunnings is fun on my e-bike, particularly the long hill back home.

I think an e-mtb is the perfect tool to assist ecologists getting around the bush without getting stuck, is less damaging to tracks, and it sure is a lot of fun. I just need to stop saying "yeeha" all the time, and probably stop smiling so much!

A WEEK IN THE LIFE OF AN ECOLOGICAL CONSULTANT: A CAUTIONARY TALE. A NON-FICTION ABRIDGED ACCOUNT OF A WEEK IN A CONSULTANT'S LIFE.

by Derek Engel in consultation with Paul Burcher

Monday.

7.30 am: The alarm has gone off and I'm lying here dreaming of the first of many coffees I'll consume today. As I do that, I run through what the day will hold: there's that proposal that came in by email on Sunday marked high priority that I'll need to address, a phone call to a client and a zoom meeting about an active project. Looking ahead I should be home in time to see my kids and help them with their homework.

9.00 am: Boot the computer up, and open my email program. Thirty-seven emails come in, of which two are worth reading, twenty want donations, seven various small African countries want to deposit money in my bank account and the rest promise that various parts of my physical and spiritual life will be improved if I just subscribe to the right program….thirty-five emails selected, thirty-five emails permanently deleted, ten minutes of my life I'll never recover. Time for a coffee. The phone rings, the number withheld, this could be a government department or a sales person wondering what ink cartridges I use. Answering it, it turns out to be a potential client who is a project manager (PM) with a large State Government Department. Part of my brain says 'damn' 'cos I'm actually low on ink cartridges!! The PM says there's an onsite start up-meeting that is planned for 9.00 am Tuesday, am I in a position to attend? The project is three hours from my home/office…sure I reply I'll be there. The PM is delighted and will need before close of business a copy of my insurances, Safe Work Methods Statement, my working near water protocol, and a proposal. If he could get it before 15.00 that would be great as he has to watch his kids play soccer. Sure, no problem. On that cheery note he hangs up and I reach for that lukewarm coffee I made ten minutes ago. Raising it to my mouth the phone rings again. It's that client I was supposed to ring first thing saying they wish to submit their Development Application today as the Council contact who they have been working with is going on six months maternity leave next week and they want her to approve their DA before she leaves. They want to submit all documents before midday just to give her time to ensure she has all she needs. I ask, have you reviewed my draft report and made any comments? His reply, I sent you an email a week ago with recommended changes. The email is located in my spam folder, it has 10 pages of 'suggested' changes…the coffee's cold by this stage.
Midday. Report updated, practically rewritten and submitted. Client's reply email just says thanks. I note he doesn't mention prompt payment of the invoice I also attached to the email I sent him. Now to sort out the documents for tomorrow's meeting, do a bit of background literature and database search, print stuff off... (Doh, printer says ink cartridges need replacing!!) but first a coffee.

With hot coffee in hand I decide to look at the two emails I didn't delete, one freaks me out, my Public Liability Insurance has expired. I knew it was due, there were just other priorities that kept it getting bumped to the bottom of the list. Several thousand dollars later and 20 minutes wasted on the phone line, insurance is paid and a promise received that an updated certificate of currency will be emailed to me shortly. God, I wish this coffee was double-strength.

1.00 pm: Zoom meeting went longer than was planned, the client forgot they were going to need an access road and asset protection zone (APZ), both of which were going to clear an endangered ecological community and push his development above the clearing threshold thereby triggering a BAM. He blamed me for not bringing this to his attention sooner…

3.00 pm: All documents submitted to the State government department and PM happy 'cos he gets to watch his kids play soccer. Doubt he even read any of them, particularly the insurances cause the updated certificate of currency still hasn't arrived.

3.00 pm: Text to my kids saying I won't be home till late as I have a proposal to write. They say it's okay Dad, but I hear in their voices it's not. I eye off the beer in the fridge but my brain and liver have decided it's a no drink week.

6.30 pm: Shut computers down and head home. Kids are showered and ready for bed. I promise I'll help them tomorrow or they could do their own homework like we did in our day!

Tuesday

5.30 am: I hate my alarm, I hate saying yes to this meeting but being self-employed I can't afford to say no, and I wonder which drive-through McDonalds is the closest so I can get a coffee.

9.00 am. There's a cast of thousands. We're all social-distancing and miming handshaking. There's so much fluoro it looks like an 80s step Reebok work out. The project is explained and a tool box meeting held. We walk over the site, all asking questions at the same time. The universal answer from the PM is, "We're not sure, we haven't worked out the finer details yet. Just assume there will be a ……<insert whatever question you have here>…………somewhere but it won't affect any waterways or bushland etc etc….". That said, we have to look at the entire 'project' area so the quote I put in for three hours including travel has blown out to five hours on-site and I doubt the PM will allow me to submit a variation.

Wednesday and Thursday

Days in the field. This is the bit we look forward to, a time to touch the trees, count the plants, birdwatch, share stories with our colleagues over a cuppa and complain that we have no work even though we're clocking six days a week. This is the part of our job we love but which pays the least. Our clients don't normally pay on field work outcomes, they want their report, they want their development application.

Do some BAM plots with Paul. I do the logs, hollow-bearing trees, stem classes and litter cover while he does the floristic plot. He starts swearing about how the veg doesn't fit any PCT, then calls me over to ask if I think there are 40 or 50 *Phyllanthus hirtellus* in the plot. Makes me happy I've stuck to fauna.

Friday

Morning email check produces a sinking feeling. The Zoom meeting client and his BAM issue has escalated, there's an email from his solicitor threatening legal action. Luckily, I have copies of his brief, my proposal, his letter of engagement, the email with the reports he provided which didn't include a Bushfire assessment and a phone log of the calls we had. None of what I have mentions APZ's or an access track. I bundle all this up and send it to my solicitor. An hour later I receive a reply from my solicitor saying the matter has been dropped but don't expect to get my $3300.00 invoice for the job paid (we all know it's not financially viable to chase this level of funds). My solicitor has also kindly attached his invoice for $250.00. So now I'm down $3550.00 and I still have subconsultants and expenses to pay. I also have to contact Council and tell them what's happened just in case my ex-client does decide to submit my report. Another waste of non-billable time.

The remainder of the day is spent writing up my field notes and starting my report from the previous two days in the field.

17.00. Screw my brain and liver, its beer o'clock.

JETBEAM BC40 PRO HAND HELD SPOTLIGHTS FOR NIGHT FIELD SURVEY

by Dr Danny Wotherspoon and Mark Mackinnon
Abel Ecology.

This is an update of our previous article (Wotherspoon 2019) about spotlights for nocturnal fauna survey, with field test results.

The OEH requirement is taken as a 12 volt 30 or 50 Watt halogen bulb:

"A minimum of 30 watts of power must be used for open forest and woodland environments. In tall or closed forests, particularly along the Great Dividing Range and coastal ranges, a minimum of 50 watts of power must be used (preferably with a gel filled 12 volt battery)" (DEC 2004)

The Mirabella lighting company has recently published data (Table 1) for halogen bulbs of various wattages in lumens output. That enables us to consider LED torches, all of which are marketed with output measured in lumens. Given that the OEH standard is 30 and 50 Watt halogen bulbs, the equivalent performance in lumens will be 500 and 800 lumens, respectively.

The CREE XHP50 LED maker claims an output of 2,150 lumens. The Jetbeam BC40 Pro emits maximum 2,930 lm for 2.6 hours and 1,817 lm for 4.4 hours. Those times are suitable for a night of spotlighting and two spare batteries are light enough to not notice in the backpack. Another key parameter is mass of the unit with batteries included. The Jetbeam BC40 Pro with batteries is 394g.

We have bought three Jetbeam BC40 Pro for $280 each including charger and spare high capacity batteries. Add in a good LED headlight for $100-200 to make a total for one surveyor of $400-500. That is a reasonable budget cost for field survey lighting.

The Field Test Verdict

Weight: The torch is not heavy and can be used for an extended time held high. We found that we move our arms around a lot when spotlighting, but the torch does not add to the arm fatigue problem. We also use light-weight Nikon Travelite binoculars (<$200) and find that we can hold both up when getting a close view of an animal. Alternatively, a colleague can hold the torch while you view with binoculars.

Heat: A significant amount of heat is produced by the LED but the long handle enables heat to dissipate and be held comfortably. Of course, on a cold night it will be most welcome warmth!

Light throw: The beam has a central fixed spot and wider beam, making it ideal for fauna spotting. The bright spot can be directed away from an animal after eyeshine is found. The reduced output button also enables longer viewing of the animal. The beam is also very bright for more than 50 metres.

Battery duration: On the test bench in the lab at our office the light did last two hours on full power. In the field more than two hours was achieved with varying the output. However, in the field one set of batteries lasted just one hour one night, possibly due to partly-charged batteries. There is a blinking warning light to show imminent loss of output, but it only gives a little time of warning.

Backups: An LED headlamp and spare batteries are necessary for every trip, and always were, but this now means a much lighter total load to carry.

Recharging: Allow overnight to charge one battery set then put the spare set back on the charger. The indicator light on the charger lets you know when the battery is fully charged.

Specific Test Surveys

We have used the torch in various environments to check how good it is:

a) Western ringtail possum, Busselton and Margaret River, Western Australia. Animals were in she-oak trees to 15 metres and dense canopy of Willow Peppermint *Agonis flexuosa* 6m to 8m tall. Possums were easy to spot and they were comfortable with the edge (umbra) beam light, resuming feeding, not stressed.

b) Cane toads, Lismore, NSW. Toads were visible on golf course fairways up to 50 metres away. "Speed-toading" on a golf buggy was very quick and efficient. We caught more toads at speed than by walking. Approaching the toads from the front enabled them to be picked up easily. Red-necked wallabies on the site were visible at more than 100 metres.

c) Forest survey Blue Mountains, NSW. Everything shows up easily in open eucalypt canopy 15m to 20m tall. Sugar gliders, Brushtail Possums, Ringtail Possums and nocturnal birds were all

Table 1: Light output of halogen bulbs in lumens

Product	GLS halogen	GU10	GLS halogen	GLS halogen	GLS halogen
Wattage	28	35	42	53	72
Lumens (lm)	360	500	600	800	1150

Source: http://www.mirabella.com.au/product-category/globes/halogen/gls-halogen/

easy to see. With the umbra (side part of the beam) lighting the animal, a common ringtail possum emerged and started feeding, unaffected by the light.

d) Dense eucalypt canopy, river flat near Windsor, NSW. In tall forest 20m to 30m tall Sugar gliders, Brushtail Possums, Ringtail Possums and nocturnal birds were all easy to see. Tree hollows also showed up well. That site had been previously surveyed with Lightforce 50W halogen spotlights but not nearly so many animals were found as with the LED light.

e) Rocky headland and estuary, South West Rocks, NSW. The bright white light was good for nearly 100 metres across the rocky headland. Light penetrated estuary water to more than a metre to see fish easily.

f) Riparian zone at Oberon, NSW frog and platypus survey. Very good penetration of clear water at night. Platypus was co-operative (as much as one ever is…) and clearly visible.

Follow-up for Light Output

For more technical detail check out LM-79 tests for light output:

https://www.enlighten.com.au/knowledge-centre/how-lm-79-testing-can-help-assess-led-luminaire-quality-performance

Recommendation

The lighting standard for fauna surveys must be updated to recognise LED lighting. Claims of light output by LED torch retailers are highly misleading. Lower power lights may be adequate if the light output can be confirmed. The Jetbeam BC40 Pro certainly performs adequately in the field for a range of environmental applications.

References

DEC (2004). *Threatened Species Survey and Assessment: Guidelines for developments and activities (working draft*), New South Wales Department of Environment and Conservation, Hurstville, NSW.

Wotherspoon, D, (2019) Hand Held Spotlights For Night Field Survey. *Consulting Ecology* (43): 10-11.

Threatened Ecological Communities: To Be or Not to Be? That is the Question

(Apologies to William Shakespeare)

Veronica Silver
Senior Ecologist, GeoLINK

An interesting debate has recently developed regarding the determination of threatened ecological communities (TECs) and the attributes used in their determination. This has arisen initially from advice from Department of Planning, Industry and the Environment (DPIE) that floristics prevail in determining a TEC and that the other two supporting factors; being landform and soil type, were not necessarily required for determination.

Subsequent to this, a letter was received for a specific site from a Council (obviously influenced by DPIE) regarding TEC determinations:

Council disagrees with the assessor that the four plant communities are not Threatened Ecological Communities due to a difference in soil type. In Section 3.2.3 of the BDAR – it is stated that due to a difference in soil type, the four Plant Community Type's (PCT's) determined for the site are not Threatened Ecological Communities (TEC's) as they are on an Aeolian landscape, as opposed to the alluvial landscape that is usually associated with these PCT's. Council disagrees with this as soil type is only one attribute that can be used to describe a TEC. Floristically, as all four of the PCT's are matched to their corresponding TEC's the BDAR must be amended to reflect this…

Determining a TEC using only floristics seems to be a bold approach by DPIE which isn't supported by Final Determinations for the TECs or previous judgements in the NSW Land and Environment Court (LEC). One NSW LEC case; Gales Holdings Pty Limited v Tweed Shire Council [2008] NSWLEC 209 found that a TEC must satisfy ALL elements in the Final Determination. Specifically, in Gale Holdings Pty Limited v Tweed Shire Council, the vegetation was not determined to be Freshwater Wetland because *"The vegetation communities do not satisfy the edaphic, locational, floristic or structural criteria specified by the Scientific Committee in its final determination."* In the same case, Swamp Sclerophyll Forest and Swamp Oak Floodplain Forest were determined not to be TECs due to the failure to satisfy certain edaphic, topographical, hydrological and locational criteria as well as certain floristic and structural criteria in the Scientific Committee's Final Determination.

In the case of Motorplex (Australia) Pty Limited v Port Stephens Council [2007] NSWLEC 74, both the floristic and locational descriptors (such as edaphic requirements, landform requirements and association with coastal floodplain) of the communities played key roles in the judgement as to whether a vegetation community was a TEC.

The Final Determinations describe what a 'particular area' is, and Gales case clearly details that for Coastal Floodplains, it's landforms that are formed by floodplain geomorphological processes. Much the same as it has for other EECs which have PCTs that occur over various lithology, but only specific lithology is the EEC. These LEC cases and many others have set a precedent on distinguishing Coastal Floodplain TECs that differs from the advice DPIE are now providing.

When examining the definition of an ecological community, the *Biodiversity Conservation Act 2016* (section 1.6) defines an ecological community as 'an assemblage of species occupying a **particular area'**. This definition closely follows modern scientific texts and embodies three requirements (Preston & Adam 2004):

i. the constituents of a community must be species;
ii. the species need to be brought together into an assemblage; and
iii. the assemblage of species must **occupy a particular area**.

From this interpretation of the definition of an ecological community, it would also seem that not just floristic attributes are required to determine a TEC. It also seems that the NSW Environment Protection Authority (EPA) are of a similar opinion that it is not only floristics that determine a TEC. The NSW EPA (2016) has mapped Coastal Floodplain EECs in State Forest using the following methodology:

"We used a combination of an existing map of coastal landforms and geology and several models of alluvial landform features to determine the likely extent of floodplains and alluvial soils in our study area. We used aerial photograph interpretation to map vegetation patterns within floodplain and alluvial areas, and to map photo-patterns likely to indicate the presence of River-flat Eucalypt Forest outside modelled areas. Over 350,000 hectares of state forest are included in our assessment".

Another Council is taking DPIE's (precautionary?) approach whereby its Development Control Plan states that *"Council considers all relevant communities that meet the floristic criteria as EECs. Their EEC status can only be challenged via appropriate soil reports."* However, obtaining soil reports would now seem to not be required according to DPIE's new interpretation of the Final Determinations.

What are the implications of this for me or my client you may ask? Choosing your TEC (or not) may have big implications when it comes to costs. For example, using the public calculator, when PCT 1235 (Swamp Oak swamp forest of the coastal lowlands of the NSW North Coast Bioregion) is designated as a TEC, credit costs are $20K. When it's not designated as a TEC, credit costs drop to $5K! It seems that the grey area of TEC determinations relates to estuarine soils. Was it the intention that coastal floodplain EECs were meant to capture dunal environments?

One further difficulty is that, as consultants, we do not have access to internal DPIE approaches to determining TECs. For example, an internal guideline for two tableland communities that applies DPIE's 'decision logic' and which takes a very technical, structured and specific approach that has no relationship with the publically available Final Determinations. How are consultants to know about these internal guidelines when they are not freely available? This particular guideline was provided with comments as part of a Request for Information by DPIE. Are there other internal approaches to TEC determination which consultants are unaware of? Why aren't these available to practicing consultants?

Perhaps a future DPIE webinar on the matter would be beneficial for our industry and prevent a lot of headaches, sleepless nights and potential court cases. Interesting times ahead…

References

NSW Threatened Species Scientific Committee (2018) *Guidelines for interpreting listing criteria for species, populations and ecological communities under the NSW Biodiversity Conservation Act 2016*, Version 2.0, March 2018

http://www.lec.justice.nsw.gov.au/Pages/publications/issues_in_focus/biodiversity_cases.aspx

Land and Environment Court of New South Wales (LEC) Caselaw Gales Holdings Pty Limited v Tweed Shire Council [2008] NSWLEC 209 https://www.caselaw.nsw.gov.au/decision/549f8d0d3004262463adfbaa Accessed 11 August 2020

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Preston BJ, Adam P (2004) Describing and listing threatened ecological communities under the Threatened Species Conservation Act 1995 (NSW). Part 1. *Environmental Planning and Law Journal* **21**, 250-263

State of NSW and Environment Protection Authority (2016). *Assessment of Swamp Oak Floodplain Forest TEC on NSW Crown Forest Estate (South Coast Region) Survey, Classification and Mapping* Completed for the NSW Environment Protection Authority.

UPCOMING ECA EVENTS

ECA ANNUAL GENERAL MEETING 2020

Date: Sunday, 1 November 2020 - 7 pm

Location: Zoom meeting. Details will be emailed to members. Contact admin@ecansw.org.au if required.

ECA ANNUAL CONFERENCE

Date: 19-20 July 2021

Theme: TBA

Location: Sage Hotel, Wollongong

PROPOSED FUTURE ECA WORKSHOPS

- **Orchid Workshop**

Date: August 2021
Location: TBA
Register your interest: admin@ecansw.org.au

- **eDNA Workshop**

Date: 2021
Location: TBA
Register your interest: admin@ecansw.org.au

- **Vegetation Community Workshop—allocating PCT's**

Date: 2021
Location: TBA
Register your interest: admin@ecansw.org.au

ECA Membership Report

Membership Category	***Total***
Full Member	
Practising Ecological Consultant	132
Early Career Ecological Consultant	15
Retired Ecological Consultant	1
Associate	
Government Ecological / Environment Officer (Associate)	27
Non-practising (Associate)	7
Student	4
Subscriber (Associate)	1
Grand Total	**187**

We have 3 new members and they are introduced below:

- Daniel Lewer (Practising Ecological Consultant)
- Alex Fraser (Practising Ecological Consultant)
- Ryl Parker (Practising Ecological Consultant)

RECENT LITERATURE AND NEW PUBLICATIONS

Book Review: Tunnels in Time by Lyndall Dawson

Martin Denny

As ecological consultants we are all involved in determining the relationship between fauna and the environment. This particularly so when addressing the status of our unique marsupials in Australia. How did the collection of marsupials arrive in Australia, why are they mainly found in this continent and what is their history in geological and human time? We are now fortunate to have on hand a publication from Dr Lyndall Dawson called the Tunnels of Time. This book endeavours to describe the discovery, ecology and extinction of Australia's marsupial fauna. It is a huge task to take on and Lyndall has had to cover a wide range of topics in her book.

The book is divided into three parts, although each part merges with the next. The first part looks at the early exploration, discovery and interpretation of the pre-history of Australia's fauna and provides interesting descriptions of some of the first discoveries of fossils. Many of the famous personalities of the early 19th Century figure in this part. In 1830 the explorer Thomas Mitchell collected fossils from Wellington Caves in central NSW and sent them to Europe for examination. This was a time when the idea that the Earth and life on it was formed gradually over a period of time and not as a collection of bones from animals occurring before 'the flood', the Creationist's hypothesis. Large bones were found in Wellington Caves and these were originally ascribed to the presence of an elephant or a dugong, but over time it was realised that there had been large marsupials inhabiting the continent. These early fossils became important in developing the ideas of Richard Owen and Charles Darwin in the Age of Enlightenment and Australia became known as a different continent from the rest of the world. Considerable information is provided about the early discovery of fossils as well as their discoverers up until the 1950s.

Part 2 continues on with discoveries and research from 1950s up to the present day and addresses many of the questions raised in earlier years. How did marsupials arrive in Australia, what was the climate in the past, what was the environment over the years and how did it change and so on. The book provides excellent figures illustrating changes over time, relating temperatures and sea levels to dominant vegetation and fauna from Early Miocene (20 million years ago) to Pleistocene (1 million years ago). Much of this section concentrates on the Pleistocene era as this was a time of great change and was associated with the arrival of humans. Why did megafauna evolve and the question of the extinction of megafauna is addressed. The book mixes the stories of those involved in research and discovery with the development of ideas and theories concerning Australia's past. This intertwining of stories holds together well and helps to retain interest in an increasingly complex subject. Throughout the book the major fossil discovery sites are described and their importance emphasised. Wellington Caves, Naracoorte Caves, Riversleigh, Mt Etna and Lake Mungo are some of the fossil sites described (there are even maps of the main cave systems at Wellington and Naracoorte).

The third part focuses on the Pleistocene era and particularly the reasons for the loss of megafauna. The fight between climate change and human interaction as the drivers of megafauna extinction is discussed fully and presented as a court case. To be able to interpret changes in fauna and the environment it is necessary to be able to accurately place a date to whatever fossil is found. Dating methods are explained with a summary table of the different methods and their limitations. Other aspects of current research include studies of teeth that can provide more than just taxonomy, but also age, sex and diet. The question of why the macropods, sufficiently large to be called megafauna, survived through time whilst the equally large short-nosed sthenurines disappeared, is examined. The author devotes a chapter to explaining the differences that possibly led to the extinction in one group and not the other – walking not hopping, diet and reproductive differences. The entry of humans (megafauna themselves) and their impacts upon megafauna populations (and the environment in general) is discussed together with climate change as an agency. Both cases are presented in detail with the conclusion that probably both were involved. As with so many scientific questions, more data is required.

The book has a common theme of tracing the history of fossil discovery and research from the early 19th century to the present day. Associated with that history are the many ideas and controversies developed by researchers, as well as the answering of questions about the evolution of marsupials in Australia. Consequently, the book has much information that would interest anyone involved in natural history. Lyndall Dawson has been involved with palaeonotological research for most of her life and brings to this book many personal stories of fellow researchers that help to make the digestion of a complex and detailed subject easier. The book is profusely illustrated with photographs and constructed figures that make a complicated topic more understandable.

If you are interested in a good read and are interested in how our unique fauna got here and how it has changed over time as well as some conjecture of its future then Tunnels in Time is for you.

This book has been self-published by Lyndall Dawson and can be ordered at lynfount40@gmail.com.

ECA RESEARCH GRANTS

2020 Grant Recipients

Grant	Recipient	Project Title	Affiliation
Ray Williams Mammal Research Grant 2019	Angela Rana	Assessing the success of the rewilding of small mammals into North Head	Sydney University
ECA Conservation Grant 2019	Gracie Liu	Moving with the times: Can movement and habitat use predict species persistence in an increasingly modified world	University of NSW
Bushfire Ecology Research Grant	Joshua Whitehead	Does fire affect the relationship between plants and their pollinators, or are they capable of rekindling things when burned out?	University of New England

Amelia Saul - ECA Conservation Grant Recipient- 2015

The relationship between the density of Lantana camara and its role as habitat for native reptiles: how does density affect the provision of ecological functions by alien species?

University of Sydney

ABSTRACT

The impacts of alien plants are often complex and include both negative and positive effects. Practitioners can be faced with the challenge of weighing up the management of alien plants against any conservation benefits that they provide. Current research focusses on mitigating the negative effects of these plants only and so there are limited tools available for practitioners to use in decision-making. Just as density-damage relationships are employed to determine the level of population control needed to curb adverse effects of aliens, here, we suggest that positive impacts of alien plants can also be related to their density. To test this, we investigated how the density (measured as percentage cover within 100 m² plots, n = 12) of invasive lantana (*Lantana camara)* is related to the abundance of native skinks (*Lampropholis* spp, surveyed with dry pitfall traps) that use the plant as refuge. We had observed that native skinks bask at the edge of lantana patches and retreat into the vegetation when approached. Therefore, we hypothesised that increasing density of lantana would provide native skinks with more edges and safe basking opportunities. Further, we expected that increasing numbers of separate lantana patches would also provide more edges for skinks to utilise. We found that skink abundance was related to

lantana density through a U-shaped relationship and linearly increased with the number of lantana patches. This suggests that benefits to native skinks only exist when lantana density is at its highest since the increase in density corresponded to an increase in the structural complexity of the plant. This growth form of lantana provided skinks with a more defined edge, and potentially more effective refuge. Therefore, density defines the positive effects as well as the negative impacts of alien plants and can be used to guide decision-making in alien plant management.

Figure 1: Native skinks (*Lampropholis delicata* and *L. guichenoti*) bask at the edge of alien *Lantana camara* patches and dart into the vegetation when approached.

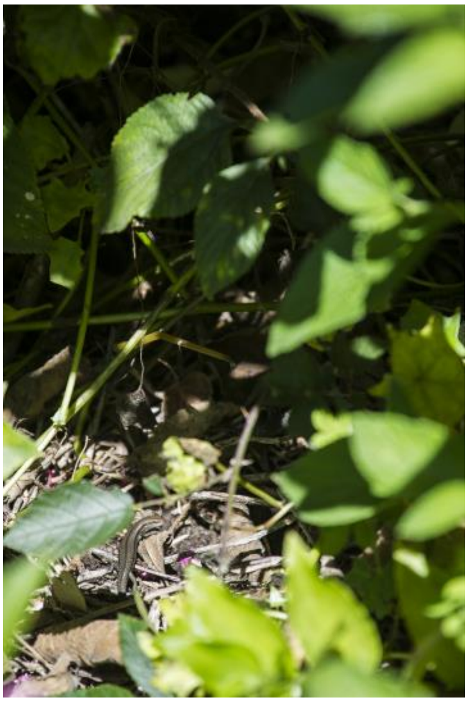


Figure 2: We surveyed native skinks using pitfall traps arranged in clusters

Figure 4: We created wire mesh guards to protect skinks in pitfall traps from kookaburras and bush turkeys. The wire mesh was secured with tent pegs but was elevated to allow skinks access to the pitfall trap.

Figure 3: Alien *Lantana camara* forms dense patches that can provide refuge to some native species. We estimated the percentage cover (m^2) of *L. camara* in 12 100 m^2 bushland plots.

Figure 5: ***Lampropholis delicata*** **in a pitfall trap. Each pitfall trap contained leaf litter and a piece of damp sponge to provide skinks with cover and moisture.**

Figure 6: Juvenile ***Lampropholis delicata*** **sampled at Bradleys Head Reserve, Mosman.**

Figure 7: Red-throated skink (***Acritoscincus platynotus*****) sampled at Bradleys Head Reserve, Mosman.**

Figure 8: We trialled a Giving-up Density experiment to test skinks' perceptions of risk at the edge and 1m away from ***L. camara*** **patches. This set up included live mealworms (provided with a carrot), in a matrix of brown lentils on a plastic plate, shaded from the sun with a plywood board. We filmed skink behaviour for 6 hours with Panasonic HX-A1 Action Cams, powered with power banks.**

Jane Williamson - ECA Conservation Grant Recipient-2017

Fire interval guidelines aimed at sustaining flora diversity: are they also sustaining fauna diversity?

Australian Catholic University

ABSTRACT

Jane Williamson[1], Murray Ellis[2], and Jennifer E. Taylor[1]

1 School of Behavioural and Health Sciences, Australian Catholic University, PO Box 968 North Sydney, NSW 2059; jane.williamson2@myacu.edu.au

2 Conservation Science Team, Office of Environment and Heritage, PO Box 1967 Hurstville BC, NSW 1481

Vegetation formations can span large geographical gradients, often with great variation in plant assemblages, soils, rainfall, and fauna habitat. Fire management prescriptions defined at formation level and based on plant responses may not capture the spatial variability in fauna habitat within formations. Our aim was to test whether the effect of fire on fauna habitat was related to vegetation class (within formation), or to recent fire history. We measured habitat characteristics (ground cover, vegetation structure, woody debris, and trees) at 54 sites within three classes of the Dry Sclerophyll (Shrubby) Sub-Formation: Sydney Hinterland, Western Slopes, and Southern Tablelands. Time since the most recent fire at all sites was approximately 6 years. Within each class, sites were grouped by interval between the most recent fire and the previous fire. These intervals were the ecologically recommended thresholds for management of this sub-formation: burnt too soon (0-6 years), appropriate (7-30 years), and too long unburnt (>30 years). Fauna habitat varied greatly within sites, but the overall composition of fauna habitat differed among classes. Field data collection is incomplete, but preliminary analyses have not shown a strong effect of recent fire history on overall fauna habitat composition, and suggest an interaction between fire history and vegetation class. There is evidence that some individual habitat components differ among fire treatments, with more hollow trees and more even distribution of woody debris on too long unburnt sites (>30years), than on sites that had the previous fire interval within the current recommended intervals. Current recommended fire intervals based only on plant responses to fire may be too coarse to capture the variability in habitat characteristics found within vegetation formations and even classes. A more holistic approach to fire management incorporating fauna habitat and at a finer scale (class level) may be more appropriate for biodiversity conservation.

Jane Williamson[1], Murray Ellis[2], and Jennifer E. Taylor[1]

1 School of Behavioural and Health Sciences, Australian Catholic University, PO Box 968 North Sydney, NSW 2059; jane.williamson2@myacu.edu.au

2 Conservation Science Team, Office of Environment and Heritage, PO Box 1967 Hurstville BC, NSW 1481

The aim of the study was to examine how data quality may affect interpretation of fire history for biodiversity conservation. Digitally stored fire records for New South Wales in south-eastern Australia for years 1902 to 2018 were used for the analyses. More than 50% of the entries in the dataset were repeated records, exaggerating the number of fires and area burnt per year by more than half in some cases (an automated clean of the datasets using software tools only identified 8% of repeated records). A manual clean is required to identify all repeated records. Sixty-three percent of records were missing an attribute important for biodiversity conservation. The number of repeated records and records with missing data has reduced dramatically in the past decade. Thirty-two years and large areas of NSW (76% of extant native vegetation in NSW and 38% in areas managed for biodiversity conservation) had no fire records, predominantly in the drier, less populated western part of the state. Evidence from newspaper archives suggest fires have occurred that are not recorded in the database. Change point analyses indicate two points of change in recorded area burnt in NSW, the mid-1930s and 1960s, although it remains unclear whether this is an actual increase over time or changes in record keeping.

WILD SNAKE HALF PIPE
A DIRECTIONAL FAUNA SAFETY BARRIER

Dr Danny Wotherspoon
Abel Ecology

Red-bellied black snake out of its natural habitat

The need to control fauna movement
Development for commercial, industrial, educational and residential use is commonly adjacent to a creek line or lagoon, with an appropriate riparian corridor of regenerated natural habitat. Public recreation areas such as soccer fields are also commonly located on low lying flood prone land adjacent to natural habitat.

Any development area adjacent to a natural habitat area poses a risk of unwanted fauna visitors such as snakes. Road kill of fauna is also a real threat to species in a local ecological community. Some species such as the endangered green and golden bell frog migrate seasonally and are at high risk of being killed by road traffic.

Under the New South Wales State *Biodiversity Conservation Act 2016* one of the questions in the five part test for EECs is

> (b)(ii) is likely to substantially and adversely modify the composition of the ecological community such that its local occurrence is likely to be placed at risk of extinction,

There is thus a need to protect fauna species from road traffic on perimeter roads that are required for bushfire protection purposes in new developments. Such road is commonly the line of interface between a development and natural habitat. The warm surface of a road or footpath is very attractive for frogs and reptiles to bask on at night.

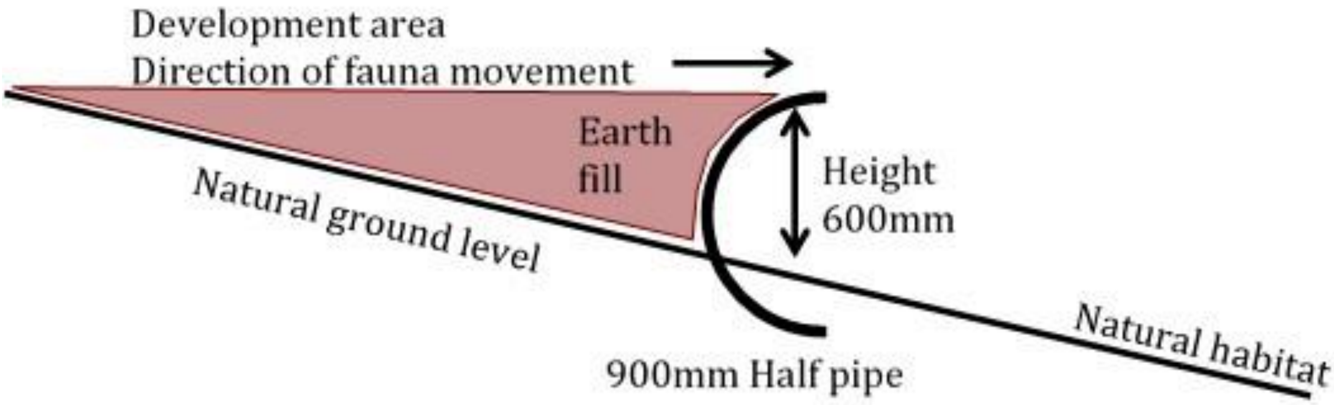
The solution is a low maintenance, robust structure that allows fauna to return to natural habitat but prevents small fauna entering dangerous (to them) urban or constructed hostile habitat such as a perimeter road.

Concept
A solid barrier is provided to enable easy small ground fauna movement in one direction but prevent or dissuade movement in the other direction.
Retaining walls are generally constructed in a form that allows small fauna, including snakes, to climb up and over.

Design example

See below for an example of how the barrier enables a dynamic response to variable terrain and boundary line. Where a retaining wall is part of the design this barrier can be installed at the base of the wall.

Cross section



Location
The interface of a development area and a retained or regenerated natural area is generally long and sinuous. A creek line or other riparian area is rarely straight so this barrier is most suitable and flexible for installation.

Construction
A concrete pipe cut to split lengthways, forming a "C" section.
Bury the pipe to one third and back fill the convex side to the top of the pipe.
The concave side is left open for two thirds the height of the pipe.
The concave side of the pipe faces the natural habitat area.
For example a pipe 900mm in diameter will have 300mm buried and 600mm as an exposed concave pipe wall.
Larger diameter pipe may be appropriate in some areas.
Bends in the wall can be achieved by angle cuts at the end of pipe sections to enable butting up of one pipe to the next and thus preclude gaps. Any gaps will be prone to erosion of fill from behind the wall. A butted angle join will be very robust and provide stability against slippage from up slope and retain integrity of the barrier.

Function
Small ground fauna (e.g. snakes, frogs) approach the pipe from the concave side and are unable to climb the curved wall. Fauna approaching from the filled convex side (area of development) can jump down to the lower level into natural habitat.
Larger fauna such as kangaroos and deer may jump over the barrier but can easily return to the natural habitat.

Maintenance
Most small fauna can climb. Any shrubs or fallen branches will enable fauna to get over the barrier. An annual pass by a labourer with a brush cutter is all that is required to make a metre wide path along the low side of the barrier.

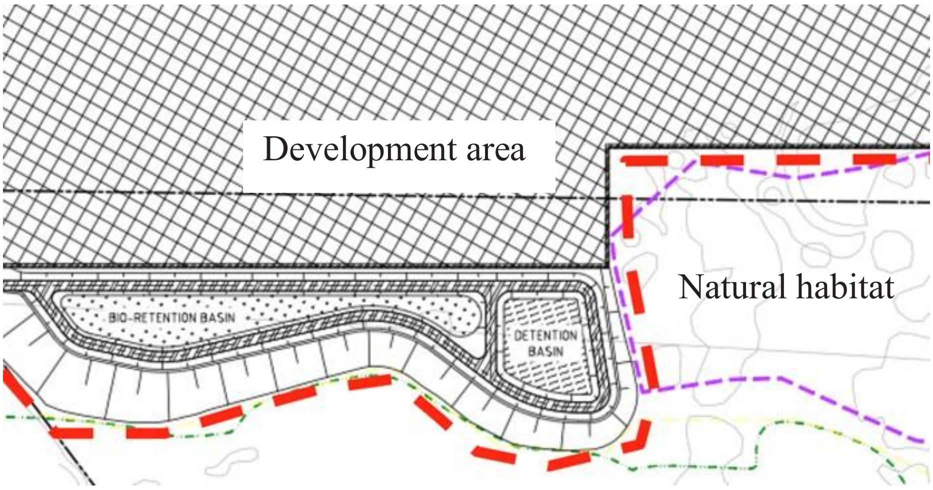
Benefits
Fauna exclusion fences are commonly specified of a drift fence design that is fragile and acts as a complete barrier to fauna movement in two directions. That design also requires intensive maintenance since large fauna such as deer and kangaroos break it down.

Flooding is unlikely to affect a Wild Snake pipe barrier whereas a flood is likely to completely destroy a standard mesh fence.

The height needs to be low enough to not be a safety hazard for people walking.
A simple post and rail fence along the top of the barrier can be installed where necessary.

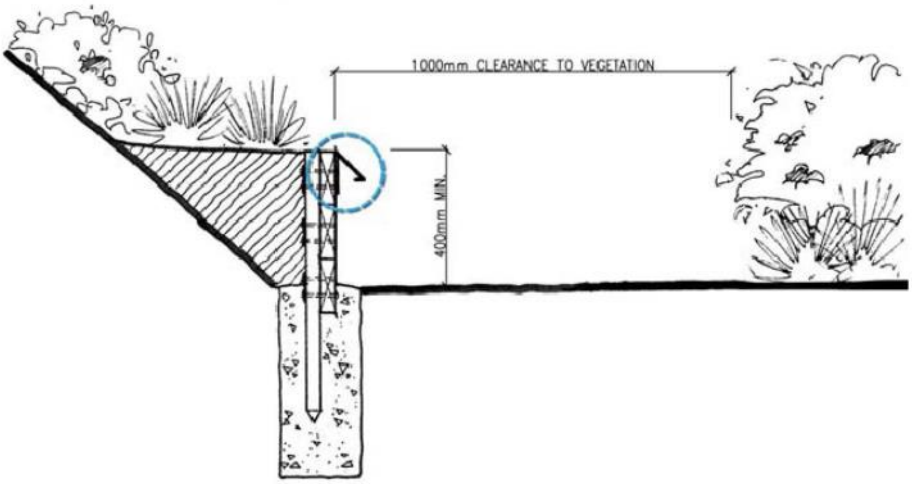
Plan view (Wild Snake Half Pipe as red dashed line)
These are design options for a potential development adjacent to a creek line.

Option 1



Option 2

Below: Alternate design from Department of Transport and Main Roads , State of Queensland (Department of Transport and Main Roads) 2010. Fauna Sensitive Road Design Manual, Volume 2: Preferred Practices.
6. Measures to achieve fauna sensitive roads.
6.11 Barriers: Fencing
Frog exclusion fence Figure 6.11.9(b) page 75



This design is more expensive to install, and not robust so will require replacement.

SUB-LETHAL IMPACTS OF PESTICIDES ON BIRDS

An edited version of an original blog posted on the Murrang Earth Sciences website, on 10 June 2020

Dr Julia Jasonsmith
Director and Environmental Chemist
Murrang Earth Sciences

When I started out in the field of contamination, I trusted that chemicals were properly evaluated for impacts and there was no need to worry about them in my day to day life. Chemists who really understood this subject would be working in companies and governments, making sure nothing happened. Over the last decade, however, I have learnt how wrong I was. Chemists, for the most part, do not understand the potential toxicological risks of the chemicals they invent and manufacture — this is not part of their training or knowledge*. The assessment of chemical impacts on ecosystems is hugely expensive and thus limited by cost, and is also usually limited to studies on very few species over short time periods, usually hours and, at most, days. And so, in 2020, chemicals are still brought to market with a paucity of data on their actual effect on the environment.

This absence of knowledge is having profound effects on the biosphere. Chemicals such as pesticides are typically evaluated for their direct effects on one representative species of a larger group — where questions such as "*what are the effects of this chemical, at this dose, on this bird we have chosen to represent all insectivorous birds*" are posed. The sub-lethal effects (described below) of these same chemicals seem only to be reported after a product has been on the market for a while and the impacts have been noticed at the population level of a species. It concerns me that these sub-lethal effects could be affecting bird populations, already under substantial environmental pressure, in such a way as to push them towards extinction.

Populations of most insectivorous and grassland bird species have declined substantially across the world in recent decades [1]. In the US, 74% of farmland species' numbers have declined since the 1960s. British farmland bird populations have decreased by 83%. In Australia, bird populations over the last 30 years have been fluctuating downwards [2]. Birds that feed on insects have seen the greatest decline, with grassland species also suffering substantially. Of the insectivores, aerial insectivores around the world are seeing some of the greatest declines [1,2].

Pesticides affect birds through secondary poisoning when they eat insects that have already consumed the pesticide neurotoxin (present in all commercial pesticides in some form [3]) or when they eat grain coated in the chemicals. Of the secondary poisoning effects, morbidity — that is, the effects of disease — and mortality— that is, death —are most often studied. We know from such studies that hundreds of millions of birds (over 90 million due to carbofuran alone in one year) have been killed from exposure to insecticides used to protect crops [1]. This is what we deem a *lethal effect* of chemical exposure.

The use of pesticides on farms is not the only factor having an impact on bird populations in these ecosystems. Decreases are strongly correlated to a change in the way farming is practiced. No- or low-input and low-intensity farming has been replaced with high-intensity high-input farming, requiring the use of fertilisers and pesticides, whilst also reducing habitat complexity [1]. Small farms have been replaced by big ones. But the use of pesticides, and the concomitant decrease in bird populations either as a result of starvation (i.e. loss of insect prey) or secondary poisoning, has been identified as the other important factor driving bird populations downwards [4,5]. Here's a quote that breaks down the impacts [1]:

"Of 122 unique studies investigating the effects of agriculture on farmland bird species, 51 (41.8%) reported negative effects from pesticides, 33 (27.1%) from habitat loss or fragmentation, 17 (13.9%) from mowing and harvesting operations, 11 (9.0%) from grazing disturbance, and 4 (3.3%) from reduced food availability."

Less well known are the impacts of what are called *sub-lethal effects* on bird populations. These effects alter the lives of animals in such a way as to cause declines in their populations even though they may not cause death or disease. Here are some examples of sub-lethal effects of pesticides known in the literature:

- Acephate (organophosphate pesticide)— altered navigational orientation of songbirds (Vyas et al., 1995; Eng et al., 017 in: [1])
- Azinphos-methyl (organophosphate pesticide) — increased begging of nesting swallows and decreased feeding by parents (Bishop et al., 2000 in: [1])
- Carbofuran (organophosphate pesticide) — impaired thermoregulation (Friend and Franson, 1999), ataxia, dyspnea, immobility, opothitonos (Hudson et al., 1984 in: [1])
- Carbaryl (carbamate) — increased begging and decreased feeding (Bishop et al., 2000 in: [1])
- Organochlorines — failure to breed, nest desertion, decreased nest defence, decreased clutch size [6]
- Dichlorodiphenyltrichloroethane [(DDT) organochlorine pesticide] — thinning of eggshells in apex predatory birds
- Imidocloporid (neonicotinoid) — reduction in food consumption, mass, and fat and probability of migration departure [7]

While some of these impacts may seem inconsequential, changes to fat-storage, thermoregulation, and ability to navigate have real impacts on outcomes for birds. How the chemicals affect the birds would be akin to humans not having a warm home or food on the table. I think it likely that these sub-lethal factors likely to be decreasing the resilience of species at a time when a heating climate, increased habitat destruction, and invasion by pest species mean resilience is needed more than ever. There is potential for bird populations to be driven further into decline as a result.

Government have responded strongly to the changes in bird populations by restricting the use of all sorts of chemicals used to protect crops. This has mainly been as a result of discovering that use of these chemicals has caused the death of non-target species [1]. The use of chemicals such as carbamates — including carbofuran, aldicarb, and mathomyl — and organophosphates — including parathion, malathion, and chlorpyrifos — have declined rapidly over the last decades after the death of hundreds of millions of birds. As is always the case, however, we replaced one chemical with another. Neonicotinoids are now the most used pesticides in the world [1] but are simultaneously being scrutinised as key drivers of bird population crashes over and above the agricultural intensification that has so impacted populations before [5].

There are organisations working to assess and limit the impact of chemicals on the environment. The Society for Environmental Toxicology and Chemistry (SETAC), for example, is a group of people working in the private sector, public sector, and non-government organisations in this field across the world. Whether you be a lawyer looking to limit the effects of chemicals, or an ecologist working to understand how these chemicals occur in ecosystems, SETAC is an organisation where concern for the impacts of pollution on our environment can be converted into action for pollution prevention.

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- I learnt this in a webinar by Professor John Warner, who developed the field of green chemistry, which aims for the manufacture of environmentally sustainable chemicals [8]

SUB-LETHAL IMPACTS OF PHARMACEUTICALS ON AQUATIC ANIMALS

An edited version of an original blog posted on the Murrang Earth Sciences website, on 30 June 2020

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We have a problem in the fields of environmental chemistry and ecotoxicology that is proving difficult to solve — the constant emission of small concentrations of many different pollutants from many different sources into waterways. Compounding this are the effects of mixtures of these chemicals to which aquatic organisms are chronically exposed. Rather than killing an animal outright, these chemicals can cause sub-lethal impacts which alter animal behaviour in a way which decreases its fitness.

Chemicals aren't just emitted to the environment from industrial and commercial activities like agriculture and mining. Many of the pharmaceuticals and health products we use on a day-to-day basis are not being captured or removed from water in sewage treatment plants, and are subsequently discharged into rivers and estuaries. The animals associated with these waters aren't just dosed once, but constantly, and for as long as they live, for as long as the chemicals are discharged, or for as long as the chemicals continue to stick around in their environment [1].

Measuring these chemicals is not a simple task and requires the specialised development of specific laboratory methods. Even if methods are developed that accurately and precisely measure chemical concentrations, assessing the impacts of these chemicals is very difficult.

There's been some research published recently that highlights the extent of the problem to some degree. A group of researchers, led by Erinn Richmond at Monash University, set out to understand whether pharmaceutical chemicals used by people can be found in watercourses in the vicinity of Melbourne [2]. The researchers also wanted to understand the potential impact of these chemicals on ecosystems. They looked at 98 different pharmaceuticals in spiders and insects, collecting these animals from rivers ranging from a reference site — that is, one where there should be no pharmaceuticals — through to sewage outfalls where pharmaceutical concentrations were assumed to be the highest.

What they found was that all insects assessed, including from the reference site, contained at least one pharmaceutical in measurable concentrations as a result of such discharges [2]. Sixty-nine different types of pharmaceuticals were found in invertebrate (both insects and spiders) samples collected for the study. The highest concentrations of pharmaceuticals occurred in organisms collected from beside the outfall of a sewage facility with tertiary (i.e. state of the art) treatment and disinfection. The most commonly detected compounds were mianserin (an anti-depressant), memantine (for alzheimers treatment), codeine (a painkiller), fluconazole (an anti-fungal), and clotrimazol (another anti-fungal).

An important discovery of Richmond et al.'s (2018) research was that the spiders that preyed on the aquatic insects contained pharmaceuticals at concentrations an order of magnitude higher than the insects themselves — this means that the pharmaceuticals were increasing in concentration up through the food web [3]. The researchers also found that insectivorous species such as platypus and native brown trout were exposed to between one quarter and one half of a human dose of some pharmaceuticals a day. In addition, rather than just the one or two highly regulated drugs to which a human would be exposed, platypuses were estimated to be consuming more than 1 mg/kg of 67 different drugs from 22 different therapeutic drug classes.

This leads to another important question in the field of ecotoxicology: What is the effect of even one of these chemicals on organisms? This is a really challenging question to answer. As a chemical risk assessor recently explained to me, different parts of an organism can be affected by a single chemical all at the same time. It's then very hard to understand whether an organ is failing because of the chemical in question or because other parts of the organism's body are affecting the organ. Sometimes a chemical can also be broken down by an organism into different compounds which may cause more damage than the chemical itself, but we may not even know to look for these chemicals in the animals. If we do know to look for them, we may not know how to measure their concentration. Thus, studying the effect of chemicals on animals in the environment (i.e. ecotoxicology) is a very challenging task. There have, however, been some developments in this area in recent years.

- In one study, again lead by scientists from Monash University, the behaviour of mosquito fish after chronic exposure to fluoxetine at environmentally relevant doses (that is concentrations known to occur as a result of pollution in the environment) was assessed, with fluoxetine an anti-depressant also found in Richmond et al.'s (2018) research. This research found that the exposed mosquito fish did not avoid predatory behaviour as they normally would and, instead, moved into the zone where they could be preyed upon [4]. This is an important sub-lethal effect, which could potentially reduce the fish's population even though these pharmaceuticals are not causing disease. Other studies of the effects of anti-depressants on fish species have identified aggression, changed reproductive behaviour, altered sociality, altered feeding rate, and altered boldness occurs as a result of exposure [5].
- Richmond et al. (2018) also found the azole anti-fungal fluconazole in many samples. Azole anti-fungals such as fluconazole and clotrimazol are known to decrease egg production, alter gonad morphology, and inhibit reproductive hormones in the fish species studied [6].
- The opioid codeine was also found in many of Richmond et al.'s (2018) samples. Opioid analgesics appear to reduce pain in fish in some cases, enabling them to continue normal behaviour in cold temperatures where they otherwise wouldn't [7]. This particular effect is disputed though, with different studies finding contradictory effects of opioids on fish [8].
- And finally, Alzheimers drugs like the memantine found by Richmond et al. (2018) are known to alter the way animals control their muscles (i.e. their motor response) and to reduce the normal movement of animals like zooplankton away from light [9]. Faria et al. (2019) also found that the habituation response was decreased in zebrafish exposed to memantine [10]. Habituation is the process by which animals learn which stimuli in an environment are associated with harm and which with benefits.

Richmond et al. (2018) assessed only 98 different drugs in their study of waterways near Melbourne. They point out that over 900 drugs are subsidised by the Australian Government, with the potential for many more drugs to be occurring in the environment. The presence of these pharmaceuticals is, in fact, now recognised as a typical feature of rivers in developed countries [8, 11, 12]. With the complexity of ecotoxicology and our difficulty understanding the effects of all these drugs on our aquatic animals, what to do about all this pollution is unclear [8].

As stated in the previous blog post, it can seem like the effects of small concentrations of pollutants are not worth worrying about and that sub-lethal effects are not of consequence to species. Yet there are clear cases where sub-lethal effects are worth worrying about, such as the crash of insect populations around the world linked with changes in behaviour due to light pollution [13]. This sub-lethal effect is, in turn, having catastrophic impacts on all the birds and mammals — including humans — that depend upon these insects for food or a fully functioning environment.

Addressing the problems presented in this blog is no easy task, with no agreement on the effects of pharmaceuticals on aquatic environments [8]. Perhaps a whole-of-life cycle assessment approach to any chemicals that might enter our waterways, including drugs, personal care products, and industrial chemicals, would prevent this pollution. Such an approach would mean that the introduction of a new drug or chemical could only happen once we are sure where in the environment it will end up and that, when it gets there, it will not cause environmental problems or the problems can be managed. Whatever the solution, we need to act to reduce the concentrations of all pollutants, pharmaceuticals and otherwise, as fast as we can.

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IMPACT ASSESSMENT AND OFFSETTING OF MICROBAT HABITAT IN BUILDINGS

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The presence of bats in buildings is not only linked to the decrease in the availability of natural cavities and for many species the buildings have become places of life. Microbats are able to squeeze through a small gap in screens, doors and windows, cracks in the roof, wall joints and the air vents to access routes into buildings. A bat colony needs an area that is protected from predators and the elements and that provides a stable temperature throughout the breeding season. Females can be very loyal to their shelters and they will return to the same locations, whether they are located in a hollow tree or in a building. Therefore, some buildings have become a prime alternative habitat for microbats especially as the supply of natural roosts decreases due, in part, to development and land-use.

A study carried out around the Bialowieza Primary Forest Reserve in Poland (Mazurska and Ruczynski, 2008) showed that although the species preferentially chose roosts located less than 100 m from the forest (the primary forest is potentially rich in cavities), many species had settled in buildings. In Hungary, Bihari and Bakos (2001) also observed greater densities of *Nyctalus noctula* in urban areas than in natural forest due, in particular, to a greater supply of roosts. However, the colonies' responses to roosting habitat loss in buildings is still widely unknown.

In Australia, the Department of Transport in New South Wales is one of a few organisations that have developed guidelines to assess and mitigate the impacts on bats under bridges and in culverts. They have been successful in rehabilitating *Myotis macropus* colonies under bridges and culverts; however, there is currently limited knowledge of the impacts of construction/destruction of buildings on these species. Mortality or injury during demolition or entrapment pose the main impact and mitigation measures and offsets are not well implemented to alleviate such impacts. There are major gaps in the process of assessing impacts and providing suitable offsets, such as retro-fitting modern building with structures suitable for species like *Myotis macropus,* and the outcomes of habitat re-creation projects are not well monitored.

For replacement roosts to be an effective measure, they should be close to the original roosts, if possible at least the same size as the original roost, installed as early as possible before the earthworks, preferably installed in combination with other roosts, offer adapted temperature conditions, be appropriate to the species, be protected from lighting and away from flight lines. While the substitution sites can be colonised by microbats, the physical displacement of colonies to replacement sites is not possible and, in the event of destruction of the roost, microbats do not necessarily choose the substitute roosts made available to them. Therefore, it is essential to find solutions or offset within existing structures. An experiment carried out in Germany on a colony of *Myotis myotis* living in a building had shown, in particular, that the bats had not remained within the proposed replacement roost (located 200m) and that members of the colony had preferred to disperse into several neighbouring colonies.

Can we learn from other countries? In Europe, a number of policies and guidelines have been developed to monitor colonies, assess any type of impact, and protect microbat species in historical monuments or other buildings where threatened microbat species occur. These guidelines are used when undertaking maintenance, construction and also renovation works. Information on known microbats populations and colony locations are provided collaboratively by consultants and the relevant Department, which is then included in the contract of sale and contractors' work contract. For instance, the French government developed and implemented the 'bats and insulation standards' and distribute a technical guide on how to take microbats into account when undertaking building insulation work. This guideline is provided to all building professionals and individuals, in collaboration with CEREMA (Centre for Studies and Expertise on Risks, the Environment, Mobility and Planning). Other mitigation measures include:

- reduction of light pollution near buildings by the implementation of reduced light levels, light covers/

shades and/or sensor lights;

- integration of different nest boxes into the building design when located near suitable habitat. The new design can be made to shelter the bats in the external parts (for example in the space between the wall and the frame) or internal parts of the buildings (for example in the attic).

- protection of settlements in farm buildings;

- consideration of microbats in old and new military sites which are often located in remote and forested area. Agreements exist between the FCEN (Federation for the Conservation of Natural Areas) and MINDEF (Ministry of Defence) to provide mitigation measures in order to protect not only the existing structures, but also to better integrate new design in buildings with different roof and cavity designs.

In New South Wales, the prescribed impact category of the BDAR does not provide any accepted guidelines on how to assess impacts, assign credits for species and subsequently offset microbat habitat in buildings as they do not have a vegetation surrogate for determination of those credits. Furthermore, the Species Credit Threatened Bats and Their Habitats NSW Survey Guide for the Biodiversity Assessment Method includes limited methods on how to assess a building for microbat habitat, but they are often not appropriate. The recommended method includes a 30-minute roost search on bridges, tunnels, culverts or other structures identified as potential breeding habitat. The guidelines recommend the use of a torch and a handheld bat detector to detect microbat activities. If microbats or signs of microbat use are observed, the bats may need to be captured to identify species and breeding status using traps, nets or other methods. The guideline remains silent in providing recommendations on survey effort in relation to the size of the roost or the practical difficulties, and safety considerations associated with inspecting potential roosts. There is a growing need to provide adequate guidance on the type of method that would be suitable for microbat surveys in buildings, including the appropriate seasonality of the survey, the use of thermal cameras and the number of survey nights.

While efforts are made to capture and record microbats across each State, there is an increased need to create better survey guidelines across Australia for species that are using buildings and/or man-made structure and make surveys consistent across the industry. There is also a need to reassess our overall impact on these species and consider all new types of habitat that may be important to threatened species. To remedy this, one of the priorities would be to integrate microbat habitats into policies related to town planning, agriculture, forest management or land use planning, based on the various legislation.

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AN INCONSPICUOUS HERB

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Rotala tripartita (Lythraceae) is a threatened species with an image problem - it slots neatly into that broad (and frustrating) category we might call 'boring and hard to identify herbs'. But according to the few sources on this species, it seems it's not just boring, but actually rare as hens teeth! The NSW Scientific Committee Final Determination for *Rotala tripartita* (2008) mentions only two locations for the species in northern NSW (Casino and South Grafton), with the Grafton location being two individuals growing on the edge of a dam (hardly anything to go on). Other records are in association with Black Swamp, south-west of Grafton near Shannon Creek and at Shannondale. The species is noted to have extreme fluctuations in abundance, with the Final Determination noting that:

> *"…plants observed to germinate prolifically and establish in large numbers after substantial rainfall. Individuals disappear above-ground during dry periods and may only persist during these times in the seed-bank."*

There are several other records in BioNet for the species, of which one site has been cleared for the Pacific Highway upgrade at Devil's Pulpit. A recent record (April 2020) for a Stewardship site near Rappville notes: *"multiple plants on the edges of melonhole gilgais in open forest - grassy woodland on floodplain".*

And that, it seems is pretty much it for records when it comes to *Rotala tripartita.*

In 2018, freshly BDAR-accredited and full of enthusiasm we began targeted surveys for species in the BAM-C at a degraded farm near Yamba, northern NSW. After five minutes of transect surveying, my colleague pointed to a little herby thing and declared it to be *Rotala*. Never having seen it before we got on our phones, checked the records, trawled PlantNET and concluded it probably was *Rotala*…and it was everywhere! A sample was despatched to the NSW Herbarium and after two nail-biting weeks we had the answer: *Rotala tripartita* it indeed was. Now we had a firm identification, we commenced thorough surveys and found *Rotala* growing liberally throughout a disturbed sedgeland at the mercy of hungry cows and the odd tractor. Around 600 plants, in fact. And since that time (to our knowledge), it has never raised its head again.

To spread awareness (and a bit of love) for *Rotala*, here's what we know from our investigations:

- Soils: Morand (2012) puts our site on the Iluka soil landscape, with limitations being acidic, highly erodible, non-cohesive soils with very low water-holding capacity and high permeability. Our site was very true to this description, a swampy, peaty soil on old sand beds with a high organic content in the surface layer and a very high water table. Surface water to about 5 cm depth was present at the time of survey.

- Timing: We recorded our plants in November 2018 and they were just commencing flowering and probably at their peak (hence easily detected). Review of other BioNet records shows *Rotala* has been recorded over various times of the year during the warmer months: January (Black Swamp), March (Shannondale, Black Swamp), April (Pillar Valley site, Rappville site), September (Casino), October (Pacific Highway - Devils Pulpit), November (Shannondale).

- Hydrology: *Rotala* seems to prefer shallow surface water and moist peaty soils, with a low tolerance for deeper water.

- Vegetation: our plants were within paddocks that had probably been cleared and grazed for at least 50 years or more, where grassland environments were mostly improved pasture, with small areas of disturbed wetland within wetter areas.

- Companion plants: typical companion species included *Baumea articulata, Baumea rubiginosa, Eleocharis acuta, Philydrum lanuginosum, Damasonium minus, Enydra woollsii, Ranunculus inundatus, Bacopa monnieri, Juncus prismatocarpus, Ludwigia peploides* and the weed species *Cuphea carthagenensis*. Several plants were also located on the verge of regrowth *Melaleuca quinquenervia* and *M. styphelioides*.

- Non-companion species: *Rotala* was not recorded where we had species such as *Baumea juncea, Schoenoplectiella mucronata, Hypolepis muelleri, Persicaria strigose* and *Schoenoplectus validus.*

- Connectivity and persistence: Our plants were isolated and occurred in a highly fragmented and modified landscape. Why were they there? How had they persisted? How is seed transported (suspected by water) and what is its longevity? Why was a single individual plant detected > 700 m from the main population and then never observed again? These are questions waiting to be answered.

- Disturbance: *Rotala* appears to tolerate grazing, trampling and slashing within wetland environments (although to what degree is unknown). We observed no signs of grazing by stock. Many seedlings were observed germinating within tractor wheel ruts. *Rotala* appears to drop out once wetland species are in low proportion within pasture areas. Some plants were found in areas of *Pennisetum clandestinum* (Kikuyu), but with scattered macrophytes.

- Similar species: the following species were all growing in /adjacent to areas of *Rotala* and could be mistakenly identified: natives - *Hypericum gramineum, Lythrum hyssopifolia, Gratiola pedunculata*; non-natives - *Centaurium erythraea, Lysimachia arvensis*.

- ID notes: In the active growing phase *Rotala* is fairly visible, growing to 30 cm in height and with a distinctive lime green colour, leaves triangular and opposite/decussate; sessile tiny white flowers in leaf axils also help (refer to photos). However, in denser sedgelands it could be easily overlooked.

Boom and bust?

It was a total fluke that we found this population, with plants recorded after a period of good rainfall, with the water table high and the weather warm - seemingly perfect conditions. Several subsequent visits to the site have not detected any plants since November 2018, although visits have been sporadic. It's likely that *Rotala* may persist in the seed bank and emerge quickly after good rainfall in warmer times and flower, set seed and die off rapidly. With its succulent form, it's likely that a population would perish quickly in very hot conditions if surface water was not present. We visited our site during several very dry and hot periods and there was no sign of the plants ever having been there. Given the dates of records in BioNet and that the species range coincides with a landscape where frosts may occur and winter rainfall is typically low, *Rotala* appears to be a species best detected from spring to early autumn.

Survey implications

The Threatened Biodiversity Data Collection (TBDC) prescribes a survey period for *Rotala* (SAII alert btw!) as between December and March only, while an earlier version of the BAM-C mysteriously suggested that survey all year round (except January) was suitable. The TBDC also has this fairly broad advice for *Rotala* survey:

"Survey within about 6 months of soaking rainfall. Species will be absent above ground if the habitat remains dry for over 6 months. Short-lived perennial, easily overlooked in the field in the dense habitat that it occurs."

Based on our experience, I would suggest *Rotala* is more likely be an annual rather than a perennial; PlantNET notes that it may be either an annual or short-lived perennial.

Conclusion

As a small, nondescript, cryptic and intermittently appearing little herb, *Rotala* is likely to be highly under-surveyed and there seems to be much to learn. In this sense, the species is yet another tricky threatened aquatic species in northern NSW, joining the ranks of Hairy Jointgrass (*Arthraxon hispidus*), Square-stemmed Spike-rush (*Eleocharis tetraquetra*) and *Maundia triglochinoides* where these species may be easily overlooked, are annuals (Rotala, Hairy Jointgrass), have a dormancy period (Square-stemmed Spike-rush) or may be confused with other similar species.

Based on BioNet records and our experience, floodplain environments between Lismore and perhaps Woolgoolga which support sedgelands and freshwater swamps which haven't been too flogged out probably broadly represent potential *Rotala* habitat. That's a fair bit of range! Getting suitable soils and the right timing and working in with the vagaries of rainfall also makes things substantially harder in getting a handle on this species. Hopefully, with a few more clued in surveyors, we might get a few more answers on how the 'under the radar' lifestyle of *Rotala* operates.

Plate 1. Rotala in fruit

Plate 2 Plants within low sedgeland of *Bauma articulata*

Plate 3 Isolated seedling in tractor wheel rut .

SOUNDING OFF ABOUT ANTHROPOGENIC NOISE: ITS IMPACTS ON TERRESTRIAL WILDLIFE AND WHY IT SHOULD BE ASSESSED PROPERLY

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1. INTRODUCTION

When assessing potential impacts of a development or activity proposal, ecological consultants often underestimate, and sometimes overlook, the impacts of anthropogenic noise. However, this form of noise is a pollutant that can alter the ecological soundscape. In turn, it may significantly aggravate the ecological impacts of habitat loss, degradation and fragmentation on fauna populations (Barber *et al*. 2010).

While anthropogenic noise impacts individuals, if enough individuals in a population are impacted by noise from a single development of activity, or the cumulative noise impacts of many developments, then it may have significant consequences at the population level. This can be manifested as a significant population decline, or a local or regional extinction. For instance, if a threatened species or population has already declined as a result of habitat loss, and then abandons otherwise suitable retained habitat to avoid anthropogenic noise, then its status could potentially become more critical. Numerous studies have already recorded reduced habitat use and lower breeding success in species and populations subjected to anthropogenic noise (e.g. Reijnen *et al*. 1995, 1996; Forman & Alexander 1998; Spellerberg 1998; Stone 2000; Lesbarreras *et al.* 2003; Peris & Pescador 2004).

The present article identifies the main sources of anthropogenic noise, known impacts on wildlife at the individual, population and community levels, and discusses measures for avoiding or mitigating these impacts.

2.SOURCES OF ANTHROPOGENIC NOISE

Sources of anthropogenic noise include:

Transportation systems. Roads and their associated vehicular traffic (e.g. Parris & Schneider 2009; Parris *et al*. 2009; Summer *et al*. 2011), airports and aircraft (e.g. Kempf & Huppop 1996; Pepper *et al*. 2003), off-road vehicles (Strauss 1990; Millspaugh *et al*. 2001; Preisler *et al.* 2006, Wisdom 2007), trains (e.g. Hanson 2008; Lucas *et al*. 2017) and ships (e.g. Erbe *et al*. 2019). Although the land surface area of roads is relatively small, the ecological effects extend well beyond their boundaries; for instance, road traffic noise impacts about one-fifth of the land area of the United States (Forman & Deblinger 2000; Forman *et al.* 2002).

Industry Noise e.g. refineries and factories, and oil and mining operations (e.g. Francis *et al*. 2011d; Blickley *et al*. 2012a,b; Schroeder *et al*. 2012).

Construction and Demolition Noise. Noise from the construction and demolition of highways, roads, buildings and pedestrian walkways. Common sources of this form of noise include pneumatic drills and hammers, air compressors, bulldozers, trucks and pavement breakers (e.g. Powell *et al*. 2006; Rasmussen *et al*. 2009; Westlund *et al.* 2012).

Sport and Outdoor Entertainment Events e.g. high-speed racing car and rally car events (e.g. (Brattstrom &

Bondello 1994), loud music events in outdoor stadiums and other outdoor public space areas (e.g. Meade *et al.* 2016), public activity in urban parks (e.g. Gonzalez-Oreja *et al.* 2012) and fireworks displays (e.g. Shamoun-Baranes *et al.* 2011).

Noise from Buildings. Examples of this kind of noise include loud music in the home, noisy social gatherings of people in outdoor areas, large air-conditioning units, electrical tools (e.g. electric saws and drills), garden maintenance equipment (e.g. lawnmowers), indoor electrical appliances and noisy pets (e.g. barking dogs).

Agricultural Noise. Use of farm machinery (e.g. bulldozers, harvesters) and pest deterrent acoustic systems (e.g. propane canons, sonic and ultrasonic devices).

Military Activity e.g. discharge of firearms, cannon-fire, explosions, low-flying aircraft (e.g. Weisenberger *et al.* 1996; Krausman *et al.* 1998, Maier *et al.* 1998; Goudie & Jones 2004).

Mobile Phone Towers, Traffic Control and Weather Radars and Wind Turbines. There is some evidence that the high sound frequencies emitted by mobile phone towers may interfere with the echolocation of bats, thus making it difficult for them to navigate and/or locate and capture prey (Balmori 2009; Nicholls & Racey 2009, 2011).

Modification of Natural Environmental Sounds. Habitat clearing or thinning may also allow natural sounds such as those produced by wind, running water and the calls of animals to travel longer distances (Rosa & Koper 2018). In addition, urban structures may deflect, absorb or amplify natural sounds, thus preventing them from travelling great distances and echoing them to different areas.

Each source type varies in amplitude (loudness), frequency (pitch), spatial (distribution) and temporal patterns (timing, duration and predictability). There is both interspecific and intraspecific variation in the sensitivity and response to anthropogenic noise (Bayne *et al.* 2008; Francis *et al.* 2009, 2011). A single individual may also vary its response temporally to anthropogenic noise; for instance, under different health and physiological conditions, age, life history stage, or due to past history of exposure to anthropogenic noise.

3. NOISE IMPACTS

3.1 Overview

Loud noise has a greater impact on fauna than does quieter noise (Weisenberger *et al.* 1996, Chan *et al.* 2010). Noise at frequencies that are similar to those used in vocalisations are most likely to interfere with animal communication and performance (Lohr *et al.* 2003). Most anthropogenic noise is at low frequencies (less than 250 MHz), which can travel long distances with relatively little energy loss (Blickley & Patricelli 2010) and is often difficult to avoid or mitigate (Singal 2005). If a sound occurs at frequencies outside an organism's hearing range, it will not have a direct impact. But if the organism can hear the sound, its acoustic energy could cause permanent or temporary hearing loss, but this might only occur when the animal is extremely close to the source of the noise (Dooling and Popper 2007).

It is often difficult to recognise the direct impacts of anthropogenic noise on fauna because they frequently occur in concert with other impacts such as increased human activity, vibration or habitat clearance, degradation and fragmentation. Even if an ecological investigator suspects that fauna are impacted by anthropogenic noise, it may not be obvious, and is often difficult to measure. An organism may show little or no response to noise in terms of habitat occupancy or foraging behaviour, but may experience strong negative impacts in terms of pairing success, number of offspring, physiological stress, or other measures of biological fitness (Francis & Barber 2013). For instance, microchiropteran bats may roost successfully under wooden road and rail bridges by day, thus giving an ecological investigator the impression that they are not impacted significantly by traffic noise and vibration. But individuals within the colony may have elevated basal levels of circulating corticosteroids (stress hormones), which at sustained levels impact adversely on their health, longevity and reproductive success.

Anthropogenic noise can impact the health, physiology and behaviour of an animal. Francis & Barber (2013) identify typical impacts in each of these response categories, and model how they may interact to have an overall impact on the biological fitness of the individual (Figure 1). These same processes can operate across part of or over the whole of an animal population, and thus impact significantly on the status (e.g. distribution and abundance) of that population. A key feature of this model is the recognition that the nature of the anthropogenic sound may influence the type and magnitude of the animal response. That is, sounds that are sudden, erratic and acute (e.g. the sound of a pneumatic drill at a nearby construction site) can be perceived as a threat by an animal, causing the animal to flee or hide. At the other end of the noise spectrum, continual or frequent ambient noise (e.g. road traffic) can mask the vocalisations of animals, thus having long-term or permanent impacts on animal communication and predation risk.

The NRC (2005) produces another model which shows the links between anthropogenic noise and the behaviour, life functions, health of individual marine mammals, and the consequent population outcomes (Figure 2). While this latter model applies to a marine environment, it could also be applied to terrestrial animals if the marine behaviours (e.g. diving) are substituted with terrestrial ones (e.g. foraging).

3.2 Behavioural Impacts

Shannon *et al.* (2015) categorise the main behavioural responses of terrestrial mammals, birds, reptiles, amphibians and invertebrates to anthropogenic noise in urban environments, and by transportation, industry and military activity. These categories are shown in Table 1 of the present article. Most noise-related behavioural changes involve:

- temporal changes in patterns of activity, e.g. songbirds singing at night when noise levels are lower than during daylight hours (Fuller *et al*. 2007).
- altered spatial distribution or movements, usually expressed as site abandonment and decreased spatial abundance (e.g. Bayne *et al*. 2008; Eigenbrod *et al.* 2008; Francis *et al*. 2009);
- decreases in foraging and provisioning activities, which are usually coupled with increased vigilance and anti-predator behaviour (e.g. Quinn *et al*. 2006; Gavin & Komers 2006; Chan *et al*. 2010; Siemers & Schaub 2011; Leonard & Horn 2012); and
- changes in mate attraction and territorial defence (e.g. Halfwerk *et al*. 2011a,b). In addition, Swaddle & Page (2007) found that noise reduced the strength of the pair bond in Zebra Finches (*Taeniopygia guttata*) because females either had difficulty identifying the calls of their mates, or pair-bond strengthening calls were masked. Therefore, the female finches are more likely to copulate with extra-pair partners, which can change the genetic and social dynamics of a population, and ultimately the population’s biological fitness.

There are many examples of bird species in urban environments changing the structure and volume of their calls in response to background noise. In Australia, this has been recorded in the Silvereye *Zosterops lateralis* (Potvin *et al*. 2011; Potvin & Mulder 2013) and the Noisy Miner *Manorina melanocephala* (Lowry *et al*. 2012). I have observed Australasian Pipits (*Anthus novaeseelandiae*) displaying and calling prominently in open, grassy median strips of busy highways. The Superb Fairy-wren (*Malurus cyaneus*) and Red-browed Finch (*Neochmia temporalis*) are among the few species that I have observed using highway underpasses, where traffic noise is both amplified and echoed as vehicles pass overhead. It would be interesting to study the vocalisations of these latter three species to determine if they are impacted significantly by traffic noise.

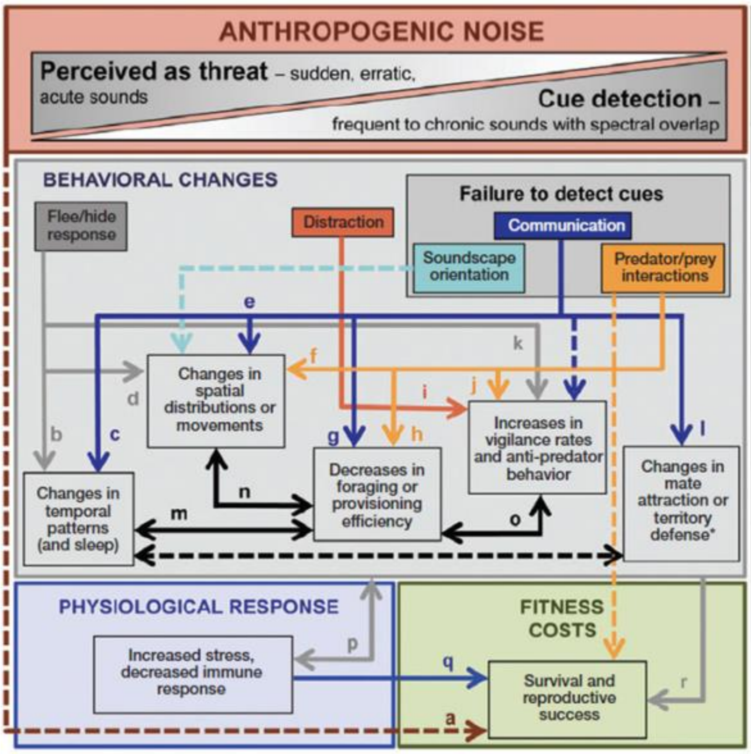

Figure 1 Relationships between behavioural and physiological responses to anthropogenic noise perceived by animals as a threat or which interferes with environmental cues, and the consequent impacts on species fitness (adapted from Francis & Barber 2013)

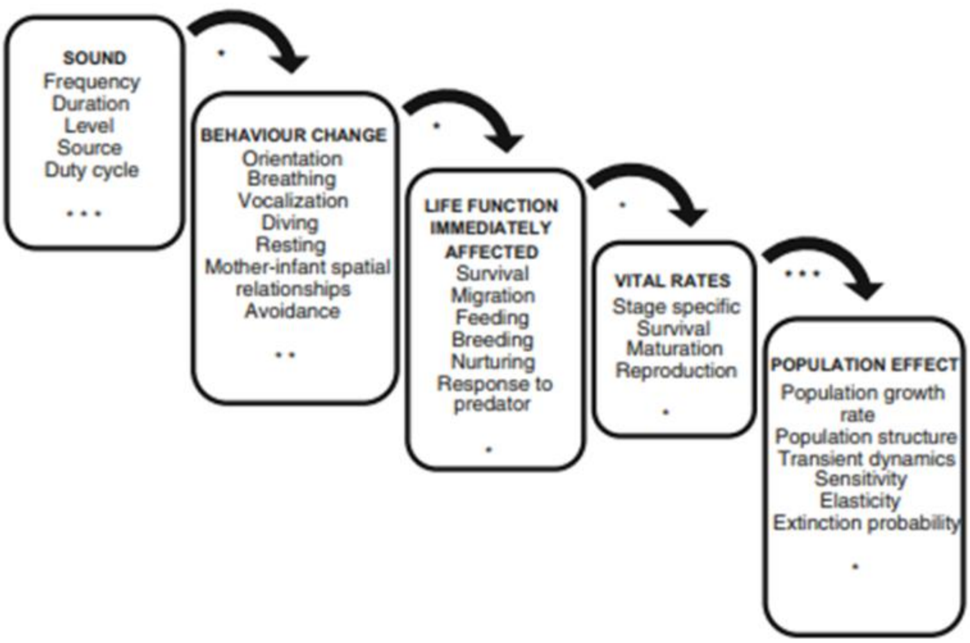

Figure 2 Flow chart of potential noise impacts on marine mammals (from NRC 2005).

The number of asterisks in each box indicate how easily the impacts can be measured. The number of asterisks under each arrow indicates how well the flow-on effects of the impacts are known.

3.3 Health and Physiological Impacts

Kight & Swaddle (2011) review the extensive literature on the physiological and health impacts of noise on animals. They show that these impacts extend to the neuroendocrine system, reproduction and embryonic development, metabolism, cardiovascular health, cognition and sleep, hearing loss, a compromised immune

Table 1 **Biological responses of terrestrial fauna to different types of anthropogenic noises (adapted from Shannon *et al.* 2015).**

References: [1] Pohl *et al.* (2012); [2] Seger-Fullam *et al* (2011); [3] Bermudez-Cuamatzin *et al.* (2011); [4] Dowling *et al.* (2012); [5] Bermudez-Cuamatzin *et al.* (2009); [6] Mendes *et al.* (2011); [7] Nemeth & Brumm (2010); [8] Hu & Cardoso (2010); [9] Proppe *et al.* (2012); [10] Slabberkoorn & Peet (2003); [11] Goodwin & Podos (2013); [12] Montague *et al.* (2013); [13] Nemeth & Brumm (2009); [14] Mockford & Marshall (2009); [15] Halfwerk & Slabbekoorn (2009); [16] Rios-Chelen *et al.* (2013); [17] Potvin *et al.* (2011); [18] Gross *et al.* (2010); [19] Redondo *et al.* (2013); [20] Pohl *et al.* (2009); [21] Nemeth *et al.* (2013); [22] Wood & Yezerinac (2006); [23] Lowry *et al.* (2012); [24] Fuller *et al.* (2007); [25] Pieretti & Farina (2013); [26] Paton *et al.* (2012); [27] Proppe *et al.* (2013b); [28] McLaughlin & Kunc (2013); [29] Kight *et al.* (2012); [30] Gonzalez-Oreja *et al.* (2012); [31] Hage *et al.* (2013); [32] Shieh *et al.* (2012); [33] Halfwerk *et al.* (2011b); [34] Potvin & Mulder (2013); [35] Verzijden *et al.* (2010); [36] Brumm (2004); [37] Arroyo-Solis *et al.* (2013); [38] Zhang *et al.* (2012); [39] Halfwerk *et al.* (2011a); [40] Crino *et al.* (2013); [41] Arevola & Newhard (2011); [42] Goodwin & Schriver (2011); [43] McClure *et al.* (2013); [44] Schaub *et al.* (2008); [45] Siemers & Schaub (2011); [46] Lengagne (2008); [47] Sun & Narins (2005); [48] Kaiser *et al.* (2011); [49] Bee & Swanson (2007); [50] Cunnington & Fahrig (2010); [51] Lampe *et al.* (2012); [52] Vargas-Salinas & Amezquita (2013); [53] Francis *et al.* (2011a); [54] Blickley *et al.* (2012b); [55] Schroeder *et al.* (2012); [56] Bayne *et al.* (2008); [57] Blickley *et al.* (2012a); [58] Francis *et al.* (2011c); [59] Francis *et al.* (2009); [60] Francis *et al.* (2012); [61] Powell *et al.* (2006); [62] Westlund *et al.* (2012); [63] Rasmussen *et al.* (2009); [64] Conomy *et al.* (1998); [65] Goudie & Jones (2004); [66] Krausman *et al.* (1998); [67] Maier e*t al.* (1998); [68] Weisenberger *et al.* (1996).

Taxa	Environmental		Transportation		Industrial		Military Activity	
	Biological Response	Noise Amplitude (dBA)	Biological Response	Noise Amplitude (dBA)	Biological Response	Noise Amplitude (dBA)	Biological Response	Noise Amplitude (dBA)
Mammals	Shifts in call frequency and amplitude by bats [31]	80	Disruption of foraging in gleaning bats [44-45]	80	Increase in physiological stress from construction noise [61-62].	52, 92	Short-term increase in heart rates and shifts in resting and movement behaviours of ungulates [66-68]	85. 98 92
					Reduced reproductive efficiency of laboratory animals exposed to construction noise [63]	68		
Birds	Changes in frequency components of vocalisations [1-22]	44-73 54, 60 59 53-80?	Changes in frequency components of vocalisations [33-35]	60-65 50	Changes in song frequency and length [53]	45	Increase in vigilance and alert behaviour [64, 65]	63 80
	Changes in call rate and duration [14-18]	60, 48-66 57	Increase in amplitude of vocalisations [36]	57	Increase in physiological stress levels [54]	52		
	Increase in amplitude of vocalisations [19-23]	54 53-62 80	Shifts in timing of vocalisations [37]	80	Reduced breeding success [55]	68		
	Shifts in timing of vocalisations [24]	63	Preference for roosting in quieter areas [38]	47	Reduced site occupancy and abundance [56-58]	48 55 45		

Taxa	Environmental		Transportation		Industrial		Military Activity	
	Biological Response	Noise Amplitude (dBA)	Biological Response	Noise Amplitude (dBA)	Biological Response	Noise Amplitude (dBA)	Biological Response	Noise Amplitude (dBA)
	Decline in species diversity [26, 27]	40 45	Effects on physiology and development [40]	60				
	Avoidance of noisy environments [28]	70?	Changes in abundance, species richness, distribution and occupancy [41-43]	46 45 55				
	Decline in reproductive success [29,30]	58 43						
Reptiles and Amphibians			Reduction in chorus tenure and duration of male frogs exposed to traffic noise [46-48]	72 60-80				
			Difficulty in locating mates [49]	75				
			Increased minimum frequency of vocalisations [50]	60				
			Change in calling time [51]	71				
Invertebrates	Shifts in energy distribution of cicada songs towards higher frequency [32]		Higher frequency components in courtship songs of grasshoppers [52]	81				

system, and DNA integrity and gene expression. However, links between physiological, behavioural responses and fitness of a population are complex and remain understudied.

The best evidence of links between physiological and behavioural responses to anthropogenic noise come from Hayward *et al*. (2011) and Blickley *et al.* (2012b). Hayward *et al*. found that faecal glucocorticoid metabolites (fGMs) in Northern Spotted Owls (*Strix occidentalis caurina*) were elevated when the birds were exposed experimentally to motorcycle traffic and motorcycle noise. Elevated fGMs are a sign that the owls were physiologically-stressed. Spotted Owls nesting in areas with higher levels of traffic noise fledged fewer offspring. Similarly, Blickley *et al*. found that Sage Grouse (*Centrocercus urophasianus*) on leks that were exposed experimentally to natural gas drilling noise or intermittent road noise also had elevated fGMs, inhibited social interactions and heightened vigilance for predators. These two examples suggest a possible causal link between anthropogenic noise, physiological stress and population fitness.

There are also likely temporal changes to physiological responses, e.g. circulating levels of stress hormone groups such as catecholamines (adrenalin and noradrenalin) and steroid hormones (cortisol, corticosterone and aldosterone) may initially be elevated in response to noise, but subside as the individual becomes habituated to the disturbance (see Fowler 1999; Romero & Wikelski 2002). Kight & Swaddle (2011) explain temporal differences in response to environmental noise in terms of "plasticity" (the ability to adapt to the noise), with community and behavioural ecology being the most plastic, and DNA integrity and gene expression being the least plastic. This then helps to define the fitness of the individual, population, species and ecological community (Figure 3).

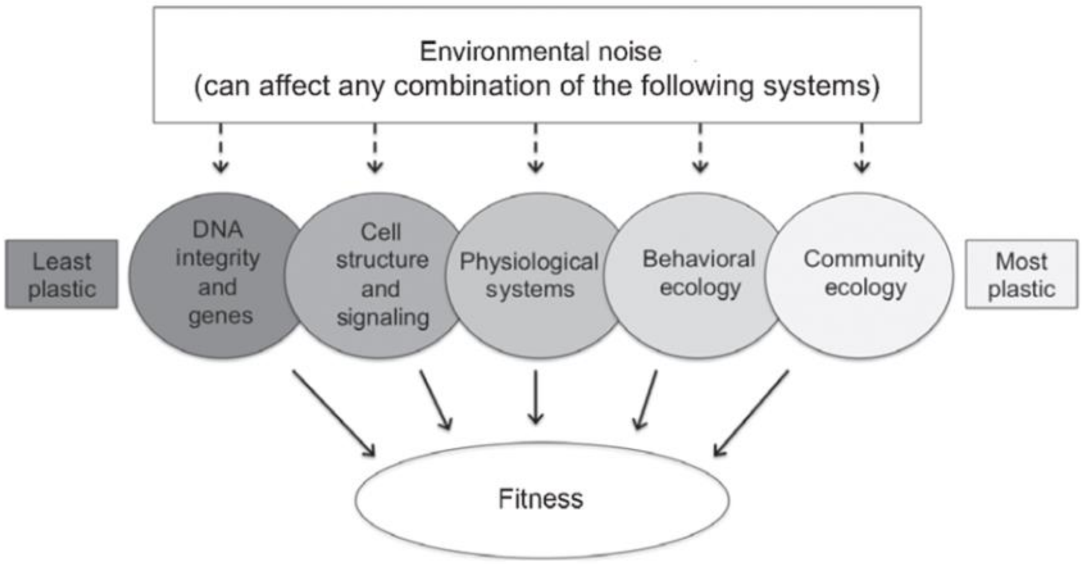

Figure 3 Plasticity of responses to environmental (including anthropogenic) noise at individual and ecosystem levels (adapted from Kight & Swaddle 2011).

4. **AVOIDANCE AND MITIGATION**

Shannon *et al*. (2015) summarise measures that have been used to avoid or mitigate noise impacts on terrestrial vertebrates. These measures are shown in Table 2 of the present article.

The most common approach to minimise noise impacts associated with transportation, industrial activity and general urban environmental noise is to erect physical barriers. But Shannon *et al*. are correct in pointing out that the effectiveness of these barriers is seldom monitored scientifically once installed, the barriers often extend only a short distance, and may compound habitat fragmentation impacts by restricting animal movements. The other forms of avoidance or mitigation are limiting noise-generating activities to times when animals are less sensitive to noise disturbances (e.g. early evening or early morning periods, or outside breeding periods), and avoidance of loud noise in or adjacent to important wildlife habitat areas.

Table 2 **Examples of mitigation measures used to reduce anthropogenic noise impacts on terrestrial fauna (adapted from Shannon *et al.* 2015).**

References: [1] Delaney *et a*l. (1999); [2] Fontana *et al.* (2011); [3] Francis *et al*. (2011d); [4] Goudie & Jones (2004); [5] Kight *et al*. (2012); [6] Lengagne (2008); [7] Maier *et al.* (1998); [8] Parris & Schneider (2009); [9] Parris *et al*. (2009); [10] Rasmussen *et al*. (2009); [11] Summers *et al*. (2011). [12] Zhang *et al*. (2012); [13] Zurcher *et al*. (2010); [14] Proppe *et al*. (2013b).

Taxa	Environmental	Transportation	Industrial	Military Activity
Terrestrial mammals		Setting criteria for height and density of road-bordering vegetation, filling in gaps between tree lines and encouraging canopy growth [13]	Noise barriers; construction scheduling to avoid noise-sensitive periods [10]	Limiting military training exercise during calving and post-calving season [7]
Birds	Urban planning (e.g. maintaining green spaces and reducing noise levels) to maintain biological communities [2]	Engineering solutions (e.g. road surfaces, tyres and vehicle engines) that reduce noise [11]	Use of sound barriers around compressors to reduce affected area by 70% and maintain occupancy and nest success rates [3]	
	Reduction of aircraft noise exposure to less than 80 dBA of river habitats used by Harlequin Ducks [4]	Closing key roads during breeding season; reducing traffic speed and volume [9]		
	Placement of new acoustically-dominant features (roads, machinery) further from nesting areas; limits to production during sensitive periods of breeding; abatement of current noise by altering structures (e.g. sound walls, dense vegetation, removing highly reflective surfaces, rerouting traffic) [5]	Use of 105 m hemispherical protection to eliminate owl flush response to over-flights; minimising flights 3 hours following sunset and preceding dawn; separating over-flights by at least seven days [1].		
		Restricting traffic flow and heavy truck use [12]. Wise planning along transportation corridors and mitigation of noise along their paths to enhance habitat for the highest number of bird species [14]		
Reptiles and amphibians	Use of noise barriers on road network; construction of new roads at distances away from protected areas; technological advances; noise with standard noise emission for vehicles, speed and driver behaviour [6]	Dense vegetation along roadsides (as a less costly alternative to solid barriers) to attenuate traffic noise [8]		

Blickley & Patricelli (2010) also promote the importance of stricter noise standards that regulate for lower and more time-sensitive anthropogenic noise levels, and for the use of construction materials that absorb noise or deflect it away from noise-sensitive habitat areas.

5. **CONCLUSION**

Overseas studies have demonstrated that anthropogenic noise pollution can potentially impact wildlife at the individual, population, species and community levels. These impacts occur in both urban and rural environments and, in some situations, could be a significant contributor to local and regional extinctions of small or geographically-confined populations. The overall impacts of anthropogenic noise in Australia are likely to increase significantly over at least the next few decades as urban areas expand into new areas, the human population increases in distribution and abundance, and human activities become more intensive and widespread. Therefore, there is an urgent need for ecological impact assessments to pay greater attention to noise impacts on wildlife, and to develop and implement more effective measures of avoiding or minimising them. There also needs to be scientifically-valid assessments of the effectiveness of these measures for each development or activity. This can be achieved through appropriate legislation and government regulation. Unfortunately, we seem to be moving in the opposite direction (i.e. less vigilant about disturbances, such as noise pollution, on the natural environment) because our environmental legislation, regulations and processes are becoming increasingly more bureaucratic (and less meaningful) and focused on habitat drivers of biodiversity protection (e.g. habitat protection and management, and biodiversity offsetting). While these drivers are important, they should not be pursued at the expense of ignoring or giving only momentary thought to other significant impacts.

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SHEDDING LIGHT ON THE ECOLOGICAL IMPACTS OF LIGHT POLLUTION

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1. INTRODUCTION

It was October 1988, in Canberra, when I first witnessed a massive Bogong Moth (*Agrotis infusa*) migratory swarm. Back then, tens of millions of Bogong Moths (Figure 1) migrated from larval feeding areas in inland Queensland, New South Wales and South Australia to alpine and sub-alpine areas of south-eastern Australia where they formed large congregations in crevices and caverns above 1400 m. The moths migrate back to their breeding grounds in late summer and autumn, usually between February and April (Common 1954, DPS 2006, Green 2006)). That year's spring migration was memorable because it was the first time that artificial light from Canberra's largest building, the New Parliament House (Figure 2), which had opened earlier that year, had diverted such large numbers of moths into the inland capital city from their usual migratory pathway.

Figure 1 Bogong Moth

(Source: www.lepiforum.de/lepiwiki)

Figure 2 Australia's New Parliament House and its reflection in neighbouring Lake Burley Griffin at night

Source: Jeremy Trow (Finding Inspiration on the Hill, https://www.abc.net.au/local/stories/2008/05/12/2242418.htm)

Three and a half years earlier, I had, for the first time, observed much smaller Bogong Moth concentrations around artificial night lights on the edges of the sports fields at the University of New England, Armidale in northern NSW. It was a surreal experience, especially for someone who had recently arrived in Armidale from Perth earlier in the year. I was not used to screeching sounds of Masked Lapwings penetrating the dense mist of late autumn /early winter nights as the birds hawked the moths that were circling the sports lights. A very ghoulish experience! But my Bogong Moth experience in Canberra was ramped up at least several tens of thousands of times, perhaps more, in comparison. Bogong Moths were everywhere in Canberra, on nooks and overhangs of windows of buildings, inside air-conditioning ducts and vents, in people's homes and places of employment, on lawns, pavements, roads, and on urban parkland, street and garden trees. Invertebrativorous birds, especially Masked Lapwings, Magpie-larks (*Grallina cyanoleuca*), Australian Magpies (*Cracticus tibicen*), Noisy Miners (*Manorina melanocephala*) and even Silver Gulls (*Chroicocephalus novaehollandiae*), hawked aerial moths by night and on stationary (resting) moths by day. Since then, the New Parliament House continues to be an artificial light beacon at night, attracting the moths every year during their two seasonal periods of migration.

While I was aware before then that artificial light pollution in the Northern Hemisphere had significant ecological impacts, my Bogong Moth experience in Canberra made me realise that it could also be a problem in Australia. Since then, I have had a personal and professional interest in the impacts of light pollution on urban wildlife. Like so many other ecological consultants, I am finding that it is becoming an increasingly more significant issue when assessing development and activity proposals in urban and industrial environments.

The present article discusses the nature of natural and artificial light, the forms of anthropogenic light pollution, and how it effects wildlife. More detailed discussion is provided on the impacts of light pollution on bird ecology, primarily because I specialise more in ornithological consultancy than on other taxa. The Australian Government has also released draft guidelines for reducing the effects of light pollution on wildlife, which I suspect will eventually lead to anthropogenic light pollution being listed as a Key Threatening Process under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act). Therefore, I discuss these guidelines in the context of the existing government regulatory framework.

2. WHY IS LIGHT POLLUTION A PROBLEM?

2.1 The Electromagnetic Spectrum and Visible Light

Light is part of the electromagnetic spectrum that comprises visible light, microwaves, radio waves and gamma rays (Figure 3). White light is a mixture of all wavelengths of light, ranging from short wavelength blue to long wavelength red light. Light that is visible to animals generally falls between wavelengths of between 300 nanometres (ultraviolet light) to over 700 nanometres (infrared light), but the range varies between species. Light with wavelengths of between 380 and 780 nm is visible to humans, and within that part of the spectrum, we perceive wavelengths of between 750 and 650 nm as red light, 640-590 nm as orange light, 580-550 nm as yellow light, 530-490 as green light, 480-460 nm as blue light, 450-440 nm as indigo light, and 430-390 nm as violet light.

2.2 Animal Vision

Animals detect light using three types of photoreceptor cells in the eye: cones, rods and Intrinsically Photosensitive Retinal Ganglion Cells (ipRGCs).

Cones are activated by bright light and allow the eye to perceive colour (photopic vision), whereas rods are activated under low light conditions, which perceive light only as shades of grey instead of colour (scotopic vision). Scotopic vision is more sensitive to shorter wavelengths of visible light (blue/violet) than is photopic vision. There are different types of cone cells in the eye, each more sensitive to a particular wavelength range within the colour part of the visible light spectrum. For instance, humans have three different types of cones that have maximum sensitivities to different wavelengths in the visible light spectrum: short cones (peak sensitivity at around 420 nm, blue light), medium cones (peak: around 530 nm, green light) and long cones (peak: around 560 nm, red light) (Figure 4; Cao & Barrionuevo 2015).

The presence, abundance, diversity and types of cones, rods and ipRGCs vary between species, all of which contribute to an animal's ability to perceive light and colour. Therefore, the level of sensitivity a species is to visible light, and the ability to see colour or not, depends in part on the abundance and composition of rods, cones and ipRGCs in the eye. Figure 5 provides examples of the perception of colour in a range of animals in correlation with the number of cone cell types. Critical to the assessment of the impacts of light pollution on animals, though, is that all animal groups that perceive light appear to be sensitive to ultraviolet, violet and blue light.

Intrinsically Photosensitive Retinal Ganglion Cells do not help form images in the brain, but align when we feel sleepy or alert and help control pupil restriction (Hattar *et al*. 2002; Graham & Wong 2008). These cells respond directly to blue light by secreting the hormone, melanopsin, which has a peak sensitivity of around 480 mm (Figure 4) (Graham & Wong 2008, Lucas *et al*. 2014). It is believed that ipRGCs also receive information indirectly about other wavelengths through interconnections with rods and cones (Lazzerini Ospri *et al*. 2017). The ipRGCs communicate directly with the brain's hypothalamus, affecting circadian rhythms and neuroendocrine regulation throughout the body.

Although cones are most active in daylight, allowing animals to see colour, some species have a greater ability to see colour than others at night (Figure 6). For instance, Kelber & Roth (2006) found that hawkmoths (*Hyles* spp.) have evolved larger lenses in their eyes, and shortened the distance that the light has to travel to get to their cone cells. This lets enough light in to allow them to detect ultraviolet, yellow and blue on a moonless night, when the only light comes from the stars. Therefore, they are as efficient in finding flowers by colour at night as are butterflies by day.

Figure 3 Electromagnetic spectrum

Source: **https://iristech.co/how-iris-reduces-blue-light/visible-spectrum/#gallery**

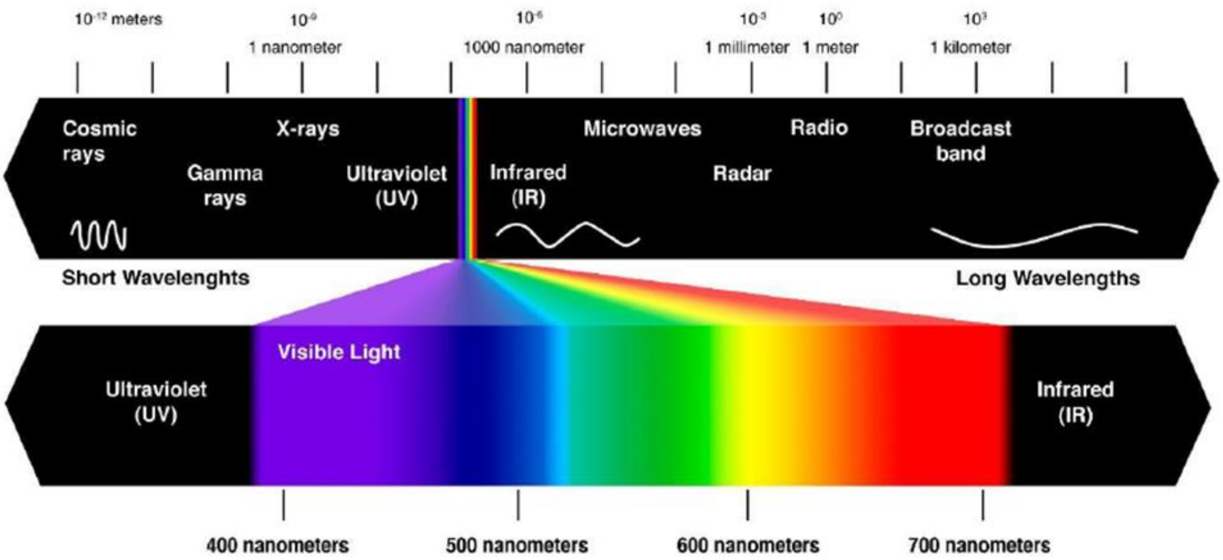
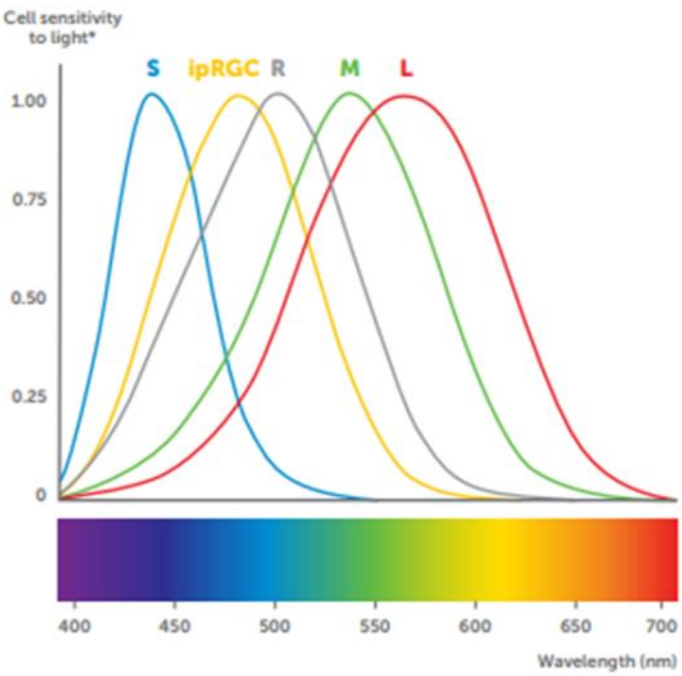
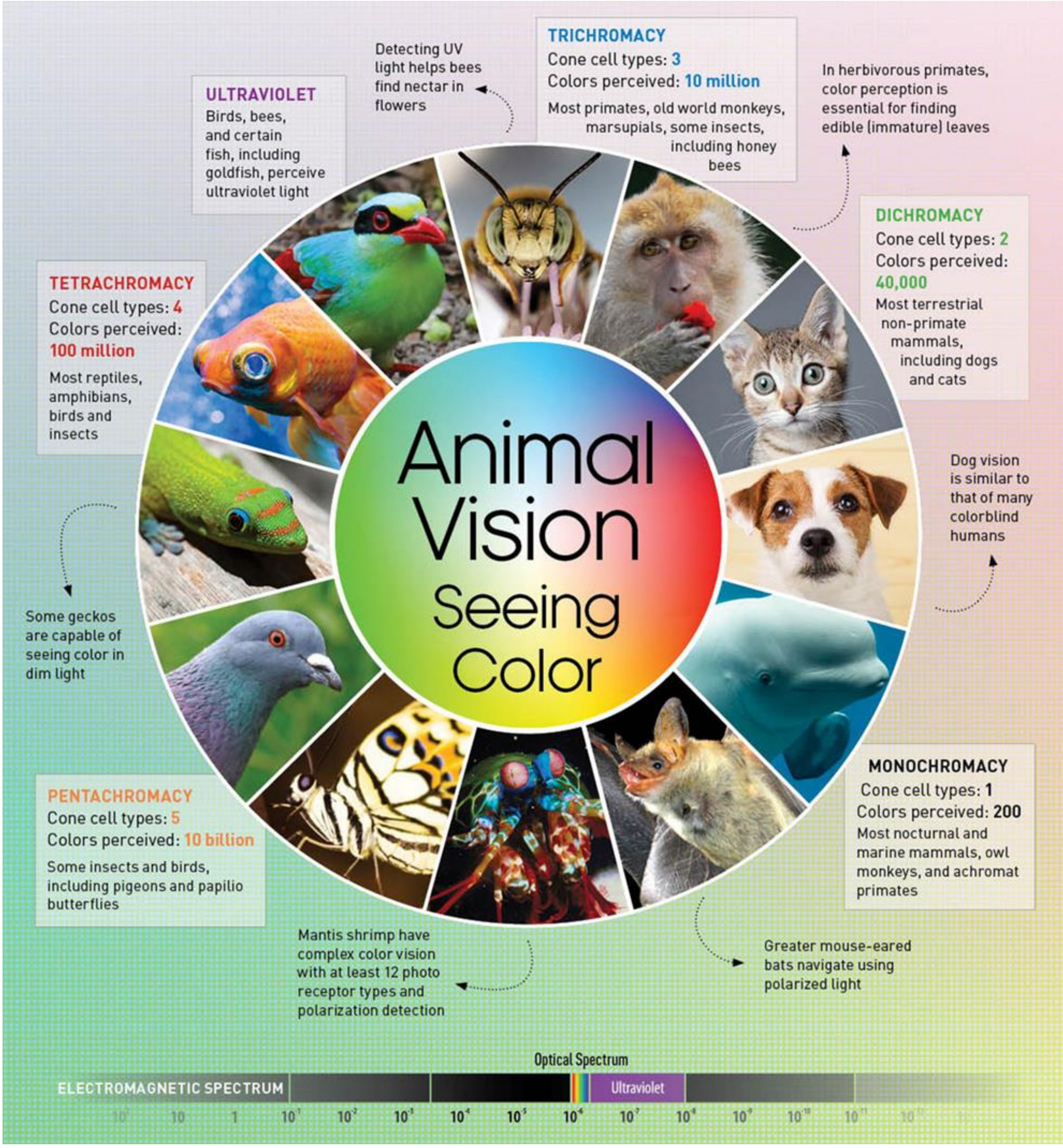


Figure 4 Spectral sensitivities to light by photoreceptor cells in the human eye (adapted from Cao & Barrionuevo 2015).



Cell type		Peak maximum
S	Short cones	~420 nm
ipRGC	Intrinsically Photosensitive (light detecting) Retinal Ganglion Cells	~480 nm
R	Rods	~500 nm
M	Medium cones	~530 nm
L	Long cones	~560 nm

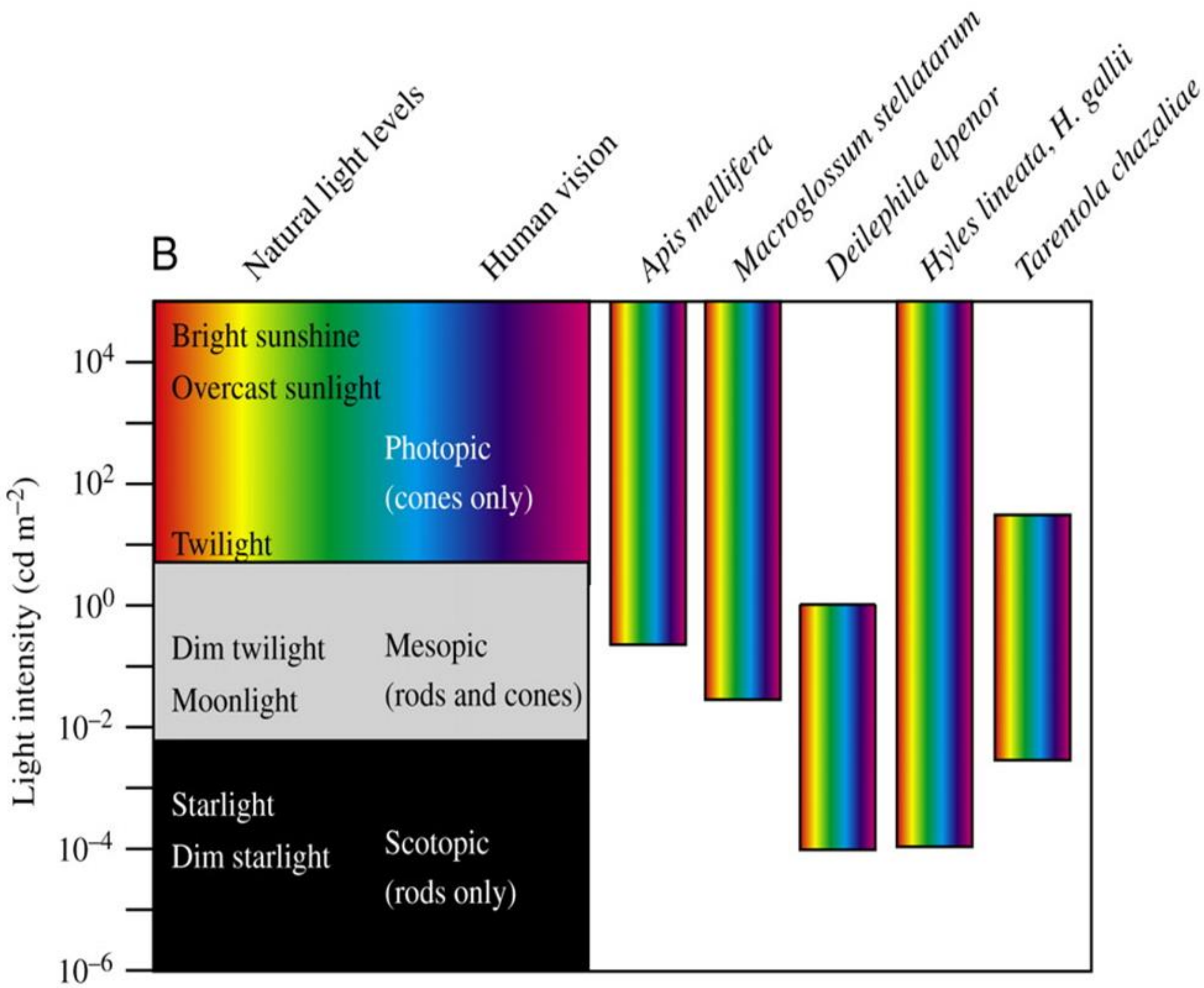
Figure 5 General differences in the abilities of species to perceive light and colour.
Source: Wikipedia/Images:Getty Images/Infographic Alessia Kirkland



Kelber & Roth (2006) also showed that the Helmethead Gecko (*Tarentola chazaliae*) had no rods in their eyes, but the cones have evolved to become more rod-like, longer and more sensitive to light. Like the hawkmoths, they also have large lenses and a shorter focal distance to cut down how far the light had to travel through the eye.

More recently, Carvalho *et al.* (2011) discovered that lemurs can detect colour at night at wavelengths from the blue to the near ultraviolet part of the spectrum. Zhao *et al.* (2009) also identified bats as having the ability to see red and blue at night. Therefore, the ability for animals to see colour at night, especially among the mammals, may be more common than currently known.

Figure 6 **Light intensity and the differing abilities of humans, the European Honeybee (*Apis mellifera*), Hummingbird Hawk -moth (*Macroglossum stellatarum*), Elephant Hawk-moth (*Deilephila elpenor*), White-lined Sphinx Moth (*Hyles lineata*), Bedstraw Hawk-moth (*Hyles gallii*) and Helmethead Gecko (*Tarentola chazaliae*) *Source*: Kelber & Roth (2006).**



2.3 Artificial Light

Artificial night light can benefit humans by providing a safer environment and prolonging recreational and work activity. But it can be detrimental to species (including humans) in the following ways:

- physiological damage to retinal cells of the eye (e.g. Algvere *et al*. 2006);
- disruption of the circadian cycles in plants and animals (e.g. West *et al*. 2010; Bennie *et al*. 2016; Russart & Nelson 2018)
- changes in animal orientation, foraging and migratory behaviours (e.g. Bird *et al*. 2004; Salmon 2006; Pendoley & Kamrowski 2015; Gaston *et al*. 2015; Warrant *et al*. 2016); and
- Elevation of basal physiological stress, potentially leading to greater susceptibility to disease, and potentially shorter lifespans and lowered reproductive success (e.g. Bradley & Altizer 2007; Spoelstra & Visser 2014; Sumasgutner *et al*. 2018).

At the level of an ecological community, light can change how species interact e.g. by altering the competitive advantage under different light conditions at night (e.g. San-Jose *et a*l. 2020). Artificial light can also impact on the availability of food for some species. For instance, the Mountain Pygmy-possum (*Burramys parvus*), listed as Endangered on the schedules of the Biodiversity Conservation Act 2016 (BC Act), feeds primarily on Bogong Moths. A recent population crash in the Bogong Moth population, and thus reduced food availability for the Mountain Pygmy-possum, is attributed largely to drought, but attraction to artificial light has led to additional significant declines outside and during the drought periods (Warrant *et al.* 2016; Commonwealth of Australia 2016). Changes in the availability of food for bats (Haddock *et al*. 2019) and fish (Bolton *et al*. 2017) have also been attributed to light pollution. Some invasive pests (e.g. Gonza'lez-Bernel *et al*. 2014) and predators (e.g. Wilson *et al*. 2019) are also known to be attracted to artificial light, increasing pressure on protected species.

Different wavelengths can also trigger responses in some species but not in others. For example, ultraviolet radiation, violet and blue light are particularly attractive to bees and some other insects (Briscoe and Chitka 2001; van Grunsven 2014).

2.4 Sensitivity to Blue Light

Short wavelength light (ultraviolet, violet and blue light) is at the high energy end of the electromagnetic spectrum, whereas red light is at the lower end. Most animal species are sensitive to light within this high-energy range, and it is detected strongly under scotopic (dark-adapted) vision. Therefore, nocturnal species are generally more sensitive to short wavelength light. Prolonged exposure to elevated levels of short wavelength light, especially in artificial light, can physically damage the photoreceptor cells in the eye, especially the ipRGCs, which seem particularly sensitive to blue light (Tosini *et al*. 2016; Green *et al*. 2018). Therefore, blue light not only physically damages the photoreceptors, but affects their roles in synchronising circadian rhythms to the 24-hour light/dark cycle (Brainard *et al*. 2015).

3. **SOURCES OF LIGHT POLLUTION**

3.1 Types of Light Pollution

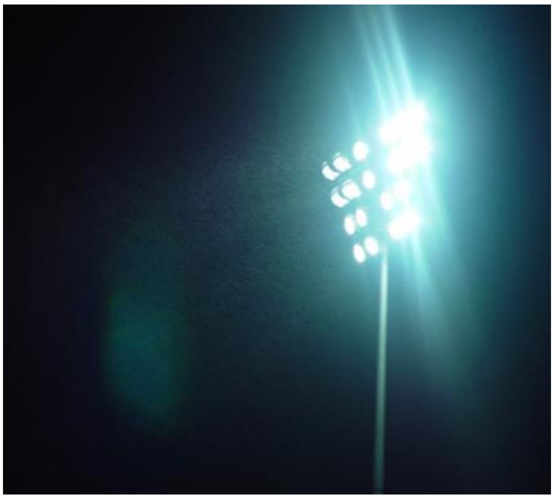
Light pollution is the presence of anthropogenic and artificial light in the night environment. It is exacerbated by excessive, misdirected or obtrusive use of light, but even light used carefully can have significant ecological impacts. Light pollution is often referred to as ALAN (Artificial Light at Night) and comes in five forms:

- **Light Trespass (spill light).** This occurs when a light fixture casts artificial light beyond property lines, illuminating other homes, businesses and wildlife habitat areas unintentionally. This is often caused by high or poorly-positioned street lights (e.g. Figures 7 and 8) or outdoor lights around the home (balcony, deck or garden lighting).

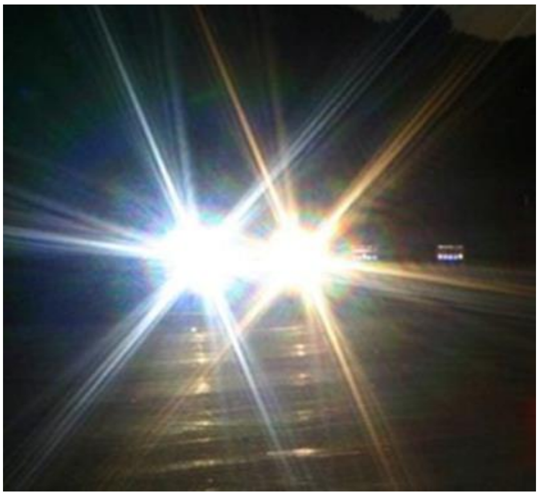
Figure 7 Light trespass from street lights in a residential setting.

Figure 8a & b. Light trespass into a wetland habitat in Sydney Park, St Peters, NSW

- **Glare.** Unshielded light strikes the eye directly from the light source, e.g. floodlights at a sports stadium (Figure 9a) and headlights of approaching vehicles (Figure 9b). Depending on the intensity of the light, glare can result in reduced visual contrast, colour perception and visual performance. Glare occurs in three forms:
  - Discomfort (psychological) glare. This occurs when lighting causes annoyance or irritation, but does not decrease visual performance, and any discomfort is short-term.
  - Disability (veiling) glare. This occurs when stray light scatters in the eye, producing a veil over the retina. This reduces visual contrast, as well as colour and spatial perception.
  - Blinding (absolute) glare. This occurs when a light source impairs the field of vision, preventing the eye from seeing anything but the light source. Visual performance may remain affected for some time after the light glare incident.



Figures 9a&b . Examples of light glare.



- **Urban sky glow**. This is light pollution that brightens the sky at night, often occurring as domes of light over cities (Figures 10a & b). It is artificial light that is either emitted directly upward into the sky or is reflected from the ground and is scattered by dust and gas particles in the atmosphere, producing a luminous background. Sky glow increases the brightness of the dark areas of the sky, which reduces the contrast of stars or other celestial objects against the dark sky background.

Figures 10a&b. Examples of urban sky glow.

- **Light Clutter.** This is excessive grouping of bright lights that cause confusion and distract from oncoming or surrounding objects. Typical examples of light clutter include light pollution from large refineries (Figure 11a) and street lights that are too bright and spaced too closely together (Figure 11b). Clutter contributes to other forms of light pollution, including light trespass, glare, and sky glow.

ECA Photo Gallery

LEFT: Female Red-capped Robin, ABOVE: Male Hooded Robin, both from near Coonabarabran. *Photo courtesy of Addy Watson.*

ABOVE: Goats! A common sight in western NSW. *Photo courtesy of Brian Wilson.*

BELOW: *Photo courtesy of Geraldene Dalby-ball.*

ABOVE: ***Acronychia littoralis.*** *Photo courtesy of Ian Colvin.*

LEFT: ***Boronia ledifolia.*** **RIGHT:** ***Bossiaea scolopendria*** *Photos courtesy of Isaac Mamott.*

ECA Photo Gallery

ABOVE: Bee busy at work on a sunflower. *Photo courtesy of Veronica Silver.*

LEFT: *Pommerhelix duralensis* feeding on the mushroom while a Myrmecia ant is watching over the snail, from near Lake Parramatta in Apr 2018. *Photo courtesy of Stephanie Clark.*

ABOVE: Munmorah Flannels. *Photo courtesy of Tim Johnson.*

ABOVE: Brolgas at Everlasting Swamp National Park, NSW. *Photo courtesy of Roxanne Zybenko-Keane*

LEFT: *Stylidium laricifolium*. *Photo courtesy of Ruby Stephens.*

RIGHT: The importance of hollows. *Photo courtesy of Veronica Silver.*

ECA Photo Gallery

LEFT: Eastern Osprey (*Pandion haliaetus*), Lane Cove National Park. *Photo courtesy of Nicholas Yu.*

RIGHT: Mid-air Combat. No, your eyes are fine....yes, the White -bellied Sea-eagle is upside down!! The White-bellied Sea-eagle took flight and was attacked by an Eastern Osprey (bird on top) which caused the Sea-eagle to flip upside down in combat. *Photo courtesy of Lynne Hain.*

LEFT: *Persoonia hirsuta* - a new population found in the Campbelltown LGA in August 2020. *Photo courtesy of Mathew Misdale.*

RIGHT: Meadow Argus (*Junonia villida calybe*). *Photo Courtesy of Nicholas Yu.*(species ID not confirmed).

LEFT: Sturt Desert Pea. *Photo courtesy of Steve Sass.*

ECA Photo Gallery

LEFT: Tasmanian landscape. *Photo courtesy of Stephen Ambrose..*

RIGHT: Yellow footed polypore (*Micropus xanthopus*). *Photo courtesy of Kim Stephen*

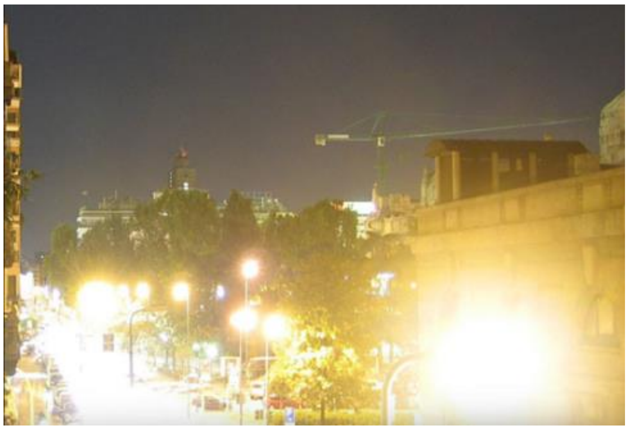
LEFT: Eastern Brown Snake. *Photo courtesy of Veronica Silver.*

ABOVE RIGHT*:* *Caladenia quadrifaria*
LEFT: *Burchardia umbellata.*
Photos courtesy of Frances O'Brien.

RIGHT: Photo courtesy of Ryan Herbert.

- **Over-illumination.** The excessive use of artificial light shone from the interiors of tall office buildings (Figure 12a) or on the exterior of landmarks or historical buildings (Figure 12b). Over-illumination often contributes to light trespass and urban sky glow.

Figures 11a&b. Examples of light clutter



Figures 12a&b. Examples of over-illumination

3.2 Blue Light Pollution

Different forms of broad-spectrum artificial white light sources have different light spectra, depending on the materials used to create the light source. To humans, white light sources vary in their colour appearance, depending on the intensity of emission of light at different wavelengths within the visible part of the light spectrum. In general, this perception ranges from warmer red-yellowish-white light to cooler and brighter blueish white light. Examples of light spectra of common artificial light sources used in Australia and New Zealand are shown in Figure 13. The Correlated Colour Temperature (CCT) is a relative measure of how yellow or blue the colour of light emitted from an artificial light source appears. It is measured in the Kelvin (K), and is most commonly found between 2200 Kelvin degrees and 6500 Kelvin degrees. Low CCT generally, but not always, corresponds to a relatively low proportion of blue wavelength light. For instance, halogen (e.g. sodium) lamps emit very little blue light, whereas mercury vapour lamps emit much more blue light (Table 1).

These spectral differences need to be taken into account when assessing the potential impacts of light pollution in wildlife. For instance, more flying insects (predominantly lepidopterans and dipterans) are attracted to white LED street lights that emit significant amounts of blue light, than to traditional high-pressure sodium street lights that predominantly emit orange light (Pawson & Bader 2014; Stanley *et al*. 2015). The ultraviolet and blue wavelengths of mercury lamps also attract significantly more flying insects (Eisenbeis & Hänel 2009).

Blue/green outdoor lighting has been shown to affect the foraging of various European bat species, increasing the activity of some, and reducing it in others (Spoelstra *et al*. 2015, 2017).

Royal Society Te Aparangi (2018) states:

"Blue/green light has been shown to help birds align in direction during migration, while red light has been shown to disrupt this orientation (Witschko et al. 2007; Poot et al. 2008), with the potential to increase the risk of birds striking communication towers (Longcore et al. 2008). Leatherback turtles are more sensitive to shorter wavelengths than other colours, moving towards blue or white light even on moonlit nights (Rivas et al. 2015). Most frogs also exhibit a blue light preference, and move towards blue light (Bucharan 2006), whereas migrating toads avoid areas of road illuminated with white or green light van Grunsven et al. (2017). Bioluminescence signals are used in sexual communication by marine species and fireflies, and operate at the 470 nm blue wavelength (Haddock et al. 2010). Artificial lighting with this spectrum could disrupt mating behaviour in these species (Longcore and Rich 2004)."

Figure 13. Light spectra of common artificial light sources available in Australia and New Zealand (from Royal Society Te Aparangi 2018).

x-axis: wavelength (nanometres); y-axis: relative intensity of emission, where 1.0 represents the highest peak in the spectrum.

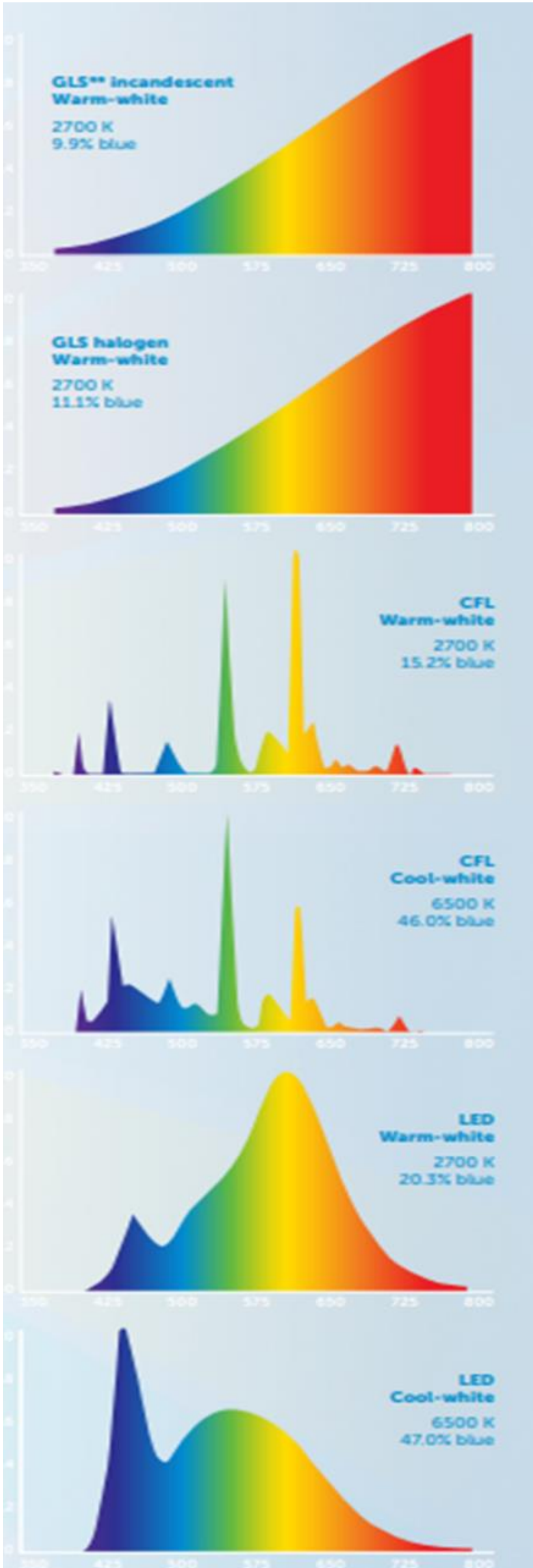


Table 1 **The amount of blue light in the selection of outdoor lighting sources at equivalent lumen output (luminous flux: 1000 lm) (from Royal Society Te Aparangi 2018).**

Light Source	Correlated Colour Temperature (K)	Percentage Blue Light
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

3.3 Assessing Ecological Impacts of Light Pollution

Taking all of the above-mentioned information into account, the following parameters need to be considered when assessing the impacts of light pollution on wildlife:

- The type(s) of light pollution (light trespass, glare, urban sky glow, etc.).
- Brightness (intensity) of the light.
- Composition of the light spectrum (wavelengths and their intensities), including a consideration of whether or not the original light energy has been absorbed, reflected, refracted or diffracted significantly in the environment before it reaches the eyes of target organisms.
- The timing and duration of lighting.
- The spatial distribution of artificial light sources.
- The extent of intrusion of the light pollution into wildlife habitat.
- Target species under investigation, their sensitivity to spectral wavelengths, their timing and use of areas polluted by artificial light, and their spatial distribution and abundance within those light spill areas.
- Impacts on the broader ecological community (e.g. prey, predators, competitors, vegetation, overall condition of wildlife habitat) if one or more target species are impacted significantly by light pollution.
- The cumulative impacts of light pollution from more than one source, and in addition to impacts from other urban disturbances.

A lot of the required ecological information may not be available because of lack of research in this area. But there has been a rapidly-growing body of research worldwide on the impacts of light pollution on wildlife, especially over the last 10 years. Therefore, ecological consultants should consult the scientific literature regularly, preferably with each new consultancy project, to aid their predictions of light pollution impacts. It is also extremely important for ecological consultants to work collaboratively with light specialists who have the expertise to measure light emissions accurately, understand the physics, and who have the ability to interpret and communicate the data in a way that can be comprehended by others.

4. ECOLOGICAL IMPACTS OF ARTIFICIAL LIGHT ON BIRDS

4.1 Introduction

I have devoted a considerable amount of time over the last 22 or so years assessing the potential impacts of light pollution on bird species and communities in relation to development and activity proposals. It has become a more significant issue as developments abut or even intrude into important bird habitat areas and migration corridors. It has certainly become more of an issue in larger cities like Sydney and Melbourne, where urban areas are expanding upwards and outwards and becoming more high-density residential over the last 5-10 years. This is further exacerbated by developments being proposed on or adjacent to land of moderate- to high-conservation value because most, if not all, other sites amenable to development have been developed.

Three groups of bird taxa, migratory shorebirds, nocturnal species (e.g. threatened owl species) and coastal seabirds are generally the focus of attention, when relevant to a development of activity proposal. This is because they are listed as threatened, migratory or marine species under the BC and EPBC Acts, and they live in habitats within or adjacent to the urban environment. But we should also be concerned about the other bird species (and other animals with which they interact) because, even though they are not yet threatened, many are known to be declining significantly in distribution and abundance. Therefore, some of the known impacts of light pollution on bird species and populations are discussed below. The discussion deliberately focuses on the ecological impacts to birds, whereas information about the vision physiology and sensitivity to light wavelengths by different bird groups should be consulted elsewhere. For instance, these latter topics are discussed in depth for seabirds and migratory shorebirds in DEE (2019).

4.2 Bird Migration

Many bird species (seabirds, migratory shorebirds and migratory land birds) are attracted to artificial light when migrating at night, especially if that light source is brightly-lit and is otherwise in a dark environment. Typical sources of this light pollution are oil rigs at sea, lighthouses, large (including tall) buildings, refineries and infrastructure that are over-illuminated or produce a lot of light clutter, and homes that are located in or adjacent to wildlife corridors that would otherwise be very dark at night (e.g. remnant forest and woodland corridors). This effect can disrupt the orientation in night-migrating diurnal birds, especially when the sky is overcast (e.g. Jones & Francis 2003; Poot *et al*. 2008; Ronconi *et al.* 2015). Disorientated flight can lead to mortality from exhaustion as a result of substantially-increased flight times, and from direct collision with the light structure. For instance, LeCorre *et al.* (2002) observed significantly-increased mortality among fledgling petrels, which died from exhaustion or predation after they were attracted to an artificial light source.

Loss *et al*. (2014) estimate that between 365 million and 988 million songbirds are killed each year through collisions with glass in the United States while migrating at night. To a large extent, this is because they are attracted to the internal and external lighting of buildings and, in the process, collide with glass that is invisible to them.

4.3 Time and Energy Budgets

Forest-breeding male songbirds near artificially-illuminated areas start their dawn chorus significantly earlier in the day than those in forested areas that are not affected by artificial light. Birds that sing earlier may be getting less sleep and may be at a higher risk of predation. Moreover, females gauge the reproductive fitness of males from the timing, duration and quality of their singing; therefore, females may be attracted to mate with lower-quality males who have been impacted by light pollution (Kempenaers *et al*. 2010). Species that start their dawn song earlier in the morning under natural conditions are affected much more by the exposure to artificial light than birds starting dawn song later in the morning. Thomas *et al*. (2002) explain this in terms of interspecific variation in eye size (early-morning songsters have relatively large eyes), a reflection of greater visual capability at low light intensities.

Other diurnal bird species can also begin feeding earlier under artificial lighting conditions. Collectively, I have spent over 13 years observing movements of woodland birds along and over the Hume and Olympic Highways in south-western NSW. Corvids, mostly Australian Ravens (*Corvus coronoides*) and Little Ravens (*C. mellori)* fly low over illuminated sections of highway at least one hour before dawn in search of freshly-killed carcasses on which to scavenge. Australian Magpies, Magpie-larks and Masked Lapwings forage on large flying insects that are attracted to street lights throughout the night, and scavenge large dead insects on or to the side of the highway in the pre-dawn period. Whistling Kites (*Haliastur sphenurus*) are also seen soaring low over the highways shortly before dawn (rather than after it) and I suspect that this species has been forced to do this before corvids and other early-morning scavengers consume the best-quality meat from fresh roadkills. While the timing of early morning activities of Galahs (*Eolophus roseicapilla*), Sulphur-crested Cockatoos (*Cacatua galerita*) and Little Corellas (*Cacatua sanguinea*) along the highways seem less affected by artificial lighting, Red-rumped Parrots (*Psephotus haematonotus*) are definite early-risers. It is not unusual to observe Red-rumped Parrots leave their night-time tree roosts well before dawn and feed on copious quantities of grass seeds on the sides of well-lit areas of the highways.

Lebbin *et al*. (2007) documents many other examples of diurnal insectivorous birds in North America feeding at night under artificial light conditionings. More locally, Silver Gulls circling the Sydney Harbour Bridge at night and hawking moths and other large flying insects that are attracted to the bridge's lights is an iconic feature of Sydney Harbour, particularly in spring and summer.

Pre-dawn activity in response to artificial light has the potential to negatively-impact on birds in terms of depletion of energy levels and exhaustion (longer days resulting in greater energy expenditure) (Kempenaers *et al*. 2010, Longcore & Rich 2004), and the attraction of predators (Miller 2006; Santos *et al.* 2010). But it may be beneficial to some individuals, if they use artificial light to advertise and patrol territorial boundaries, attract the best mates through courtship song, and if they are early arrivals at a rich source of food.

Night light can also increase the nocturnal activity of birds that live in illuminated habitats, especially nocturnally -foraging waders (shorebirds) (Santos *et al*. 2010; Dwyer *et al*. 2012). Positive outcomes of this situation include improved foraging success by allowing shorebirds to exploit sites that are illuminated (e.g. by streetlights), and in more widely-illuminated areas, providing shorebirds the opportunity to visually forage for prey on mudflats and sandflats (in preference to tactile foraging, which is a less successful foraging strategy). However, shorebirds generally choose their nocturnal roosts away from brightly-lit locations and avoid flying long distances between roosting and foraging areas to minimise energy expenditure (Dias *et al*. 2006; Rogers 2006a & b). Therefore, this may preclude shorebirds from foraging in what is otherwise good foraging habitat. Or they may use these foraging habitats and expend more energy travelling to and from them, increasing their predation risk and reducing their ability to build up fat reserves and complete their feather moult in preparation for long-distance seasonal migration. There is also some evidence that some shorebird species are more sensitive to artificial light than others; therefore, the composition of foraging shorebird communities, and the level of competition between species, may be altered (Hockin *et al*. 1992; Santos *et al*. 2010; Dwyer *et al*. 2012). These issues have become particularly relevant along the east coast of Australia in recent years, where there have been numerous contested large-scale residential developments proposed in areas adjacent to important migratory shorebird roosting and foraging habitat. Equally so, there have been uncontested and approved large-scale rezonings of riverside land in Sydney within the last 10 years, especially along the Paramatta River, which have resulted in tall buildings shading important shorebird roost and foraging sites during the day and spilling light onto them at night.

4.4 Seasonal Timing

Under natural conditions, longer daylight hours stimulate gonadal growth and body fattening in birds, in preparation for breeding (Gwinner 1999; Dawson 2008). Birds subjected to longer daily light regimes in laboratory experiments undergo gonadal growth (e.g. Rowan 1995; Lambrechts *et al*. 1997; Dawson *et al.* 2001; te Marvelde *et al*. 2001). It is not clear if artificial light in urban environments has the same effect, but it is possible because artificial light intensity at night can exceed the light intensity and duration thresholds that stimulate gonadal growth (Spoelstra & Visser 2014). However, this impact may be confounded by other environmental influences such as ambient temperatures and food availability, both of which are critical in the timing of egg-laying (te Marvelde *et al.* 2001).

4.5 Reproductive Success

Very little is known about the impacts of artificial light on the reproductive success of birds. A major influence is likely to be the availability of food at the time of nesting and dependency of young. For instance, Titulaer *et al*. (2012) found that Great Tits (*Parus major*) exposed to artificial light delivered insect food more frequently to chicks in the nest. On the one hand, this may be beneficial to the chicks because they are fed more food, but also potentially detrimental because the more frequently the adults travel to and from the nest, the greater is the risk of attracting the attention of predators. There may also be a significant energy cost to the adults associated with increased flight times to and from the nest.

Artificial light can also influence where birds nest. For instance, de Molenaar *et al.* (2006) observed that the early Black-tailed Godwit (*Limosa l. limosa*) arrivals to the breeding grounds chose nest sites at a greater distance from artificial lights than the late-arriving birds. However, it is not known if nests located in artificially-lit areas result in lowered reproductive success, which could occur as a result of increased predation and/or increased distractive behaviours of attending birds.

These types of considerations are of particular relevance to the assessments of impacts of proposed developments on NSW threatened owl species and their prey. For instance, the Powerful Owl (*Ninox strenua*), although a listed threatened species under the BC Act, is relatively abundant in the greater Sydney area. There is a growing conflict between the need for residential development and the protection of Powerful Owl breeding and foraging habitat, especially in the Lane Cove River and Georges River Catchment Areas, the Northern Beaches area and, to a lesser extent, in the Parramatta River Catchment Area. The locations of Powerful Owl territories and nesting trees in the Greater Sydney Area have become better documented as a result of a citizen-science project co-ordinated by BirdLife Australia, data which help ecological consultants with their assessments of impacts of proposed developments on this species. In turn, this has resulted in development proposals being modified and, in some cases, refused on the basis that the impacts on Powerful Owls are too significant. One of the recognised threats to the Powerful Owl under the BC Act is stated as:

" [The Powerful Owl] *can be extremely sensitive to disturbance around the nest site, particularly during pre-laying, laying and downy chick stages. Disturbance during the breeding period may affect breeding success."*

In addressing this threat, ecological consultancy reports that I have reviewed focus on noise and vibration impacts during demolition and/or construction, barking dogs, and increased and louder human activity during the occupancy (post-construction) period. Few of these reports pay serious attention to the potential of significant impacts of light spillage into Powerful Owl habitat. I have provided expert advice in the Land and Environment

Court of NSW on this issue for a number of contested projects, especially over the last two years, because the initial impact assessments had not considered in detail the potential impacts of light pollution on foraging and consequent breeding success of Powerful Owls.

5. NATIONAL LIGHT POLLUTION GUIDELINES

A really important document that has just been released by the Commonwealth Government is the Draft National Light Pollution Guidelines for Wildlife (DEE 2019) https://www.environment.gov.au/biodiversity/migratory-species/draft-national-light-pollution-guidelines. The aim of these guidelines is for artificial light to be managed so wildlife is:

- not disrupted within, nor displaced from, important habitat; and
- able to undertake critical behaviours such as foraging, reproduction and dispersal.

It provides an overview of the known impacts of light pollution on wildlife, especially marine turtles, migratory shorebirds and seabirds and a set of principles for mitigating light pollution impacts on the ecology of the urban environment. It also identifies government regulatory considerations for the management of artificial light around wildlife. A considerable section of the document also provides guidance to lighting specialists on the instrumentation and the most appropriate methods to be used in measuring light pollution. Therefore, the document has a lot of value for ecological consultants, lighting experts, council officers assessing development applications, the legal profession, and members of the general community who are interested in or concerned about anthropogenic light pollution.

The guidelines recognise that natural darkness has the same conservation value as clean water, air and soil, and should be protected through good-quality lighting design. In promoting this overall principle, it prescribes the following management principles to reduce light pollution:

- start with natural darkness and only add light for specific purposes;
- use adaptive light controls to manage light timing, intensity and colour;
- light only the intended object or area – keep lights close to the ground, directed and shielded;
- use appropriate lighting;
- use non-reflective, dark-coloured surfaces; and
- use lights with reduced or filtered-out blue, violet and ultraviolet wavelengths.

There are also two Australian lighting standards that provide for human safety, but also limit unnecessary light pollution. These are:

- Australian Standard DR AS/NZS 1158.3.1:2018 *Lighting for roads and public spaces pedestrian area (Category P) lighting*. This provides minimum light performance and design standards for pedestrian areas.
- Australian Standard *AS/NZS 4282:2019 Control of the obtrusive effects of outdoor lighting*. This provides for consideration of environmental concerns, and is the regulation that is of most use to ecological consultants who wish to recommend ways to minimise light pollution impacts on wildlife.

The Australasian Dark Sky Alliance (ADSA) https://www.australasiandarkskyalliance.org/, a non-government organisation dedicated to reducing light pollution has also recently set up a certification scheme that recognises luminaires that meet the requirements of the Australian and New Zealand lighting standards and the Draft

National Pollution Guidelines. There are three categories of ADSA certification:

- □ ADSA-approved: a luminaire delivering appropriate levels of performance for use in dark sky-friendly lighting designs.
- □ ADSA-prized: a higher-level of luminaire management and performance, providing even greater control over sky glow and associated light pollution, as well as glare and other human factors.
- □ ADSA-prized Wildlife Sensitive: for luminaires potentially impacting areas where sensitivities of the local wildlife take priority.

Therefore, the need to recognise and manage light pollution in Australia is likely to be strengthened over time through the implementation of appropriate legislation and regulation. In the meantime, as ecological consultants, I hope that you will take more detailed consideration of the impacts of light pollution on wildlife, and that the information provided in the present article assists you in this process.

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Some interesting predator interactions captured on a remote camera. Photos courtesy of Alison Hunt.

IS ARTIFICIAL NIGHT LIGHT HARMFUL TO AUSTRALIAN OWLS?

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1. INTRODUCTION

Some Australian owl species seem to have adapted reasonably well to living in or on the edge of urban environments. But they face increasing ecological pressure as urban development clears more of their habitat, intrudes into it, or edges right up against it. Part of that pressure is the spillage of light pollution into important owl habitat at night. To understand the potential effects of that pollution, we need to understand the anatomy and physiology of owl vision, the ecology and habitat preferences of owls, the sensitivities of owl species and their prey to light, and ways in which these impacts could be avoided or mitigated. The present article examines these issues, first in relation to a broad range of owl species, then focusing on NSW threatened owl species.

2. OWL VISION

2.1 Morphological adaptations to Low Light Conditions

The pupils in an owl's eye dilate more widely than those of most other vertebrates at comparable low levels of light, allowing additional light to enter the eye. The two pupils also open and close independently of one another. Therefore, each pupil responds to the illumination around the corresponding eye.

Humans have smooth muscle in the iris, which contracts slowly. Therefore, when light conditions change suddenly (i.e. from bright light to darkness or vice versa), our eyes take time to adjust. In contrast, the irises of owls (and other bird species) have striated muscle, which contracts or relaxes rapidly. This helps owls to navigate through a broad range of conditions from dark forests to bright moonlit open spaces in a single flight.

The owl retina has far more rods than cones and they occur in greater densities. Cones are activated by bright light and allow the eye to perceive colour (photopic vision), whereas rods are activated under low light conditions, and perceive light only as shades of grey instead of colour (scotopic vision). Some owl species have up to one million rods per square millimetre of retina, which is about five times the density of rods in humans.

Cones are also reduced in number and density, the extent to which this has occurred depends on the owl species and whether or not they are nocturnal, crepuscular (twilight) or diurnal hunters. For instance, the rod-dominated retina of the Barn Owl (*Tyto alba*) comprises 93% rods and 7% cones (Oehme 1961). The fovea is a depression in the inner retinal surface, the photoreceptor layer of which is entirely cones and which is specialized for maximum visual acuity. It is found in the eyes of mammals, birds, reptiles and many fish. In owls, the fovea is less well-developed and, in some species (e.g. Barn Owl), is not visible anatomically (Oehme 1961; Fite and Rosenfield-Wessels 1975). The ganglion cells associated with the owl fovea are also less dense and are weakly-developed (Wathey & Pettigrew 1989).

Cones of birds and reptiles contain oil droplets; different cone cell types have oil droplets of different colour and are thought to play a role in colour vision (Vorobyev 2003). However, these droplets reduce the amount of light available to the visual system (Wilby 2015). Therefore, in addition to reduced numbers of cones, owls have lost two types of oil droplet: opsin (which helps other bird species detect ultraviolet light), and red oil droplets (which is needed to detect infrared radiation) (Hoglund *et al*. 2019).

The owl's optic nerves also carry messages to the brain at a rate faster than in most other vertebrates, increasing the efficiency of detecting and reacting to visual cues, such as the slightest movements of prey or predator species.

The owls also have large eyes (especially a large cornea and lens) relative to head size. This allows for a much larger retinal surface area which, in turn, allows for more photoreceptors. Each eyeball is also tubular- rather than spherical-shaped. This allows the lens to be set further back from the retina, giving the eye a long focal length. This provides for improved distance vision similar to high-powered binoculars, i.e. a smaller field of view, but a detailed image of objects far away.

Because the eyes are so large, there is no room in the skull for muscles to rotate the eyes. Therefore, the eyes can only look straight ahead, each held in place by a bony sclerotic ring (Figure 1). This means the owl has to move its whole head to see to the side. An owl's neck is long and flexible, comprising 14 cervical vertebrae. All owl species are able to swivel their neck for greater than 90 degrees. For instance, the Burrowing Owl (*Athene cunicularia*) in North and South America is able to swivel its forward-facing head 180 degrees to the left and right, giving it a 360 -degree field of view. An owl's neck can also bend to the sides until the head is turned upside down. Strong striated neck muscles allow owls to swivel there neck quickly.

Figure 1. An owl skull showing the sclerotic ring around the eye socket.

Source https://www.reddit.com/r/pics/comments/4lvck4/owl_skull_showing_bony_structures_called/

The eyes of owls are located on the front of the head, unlike other bird species which have eyes on the side of the head. Therefore, owls have binocular vision where the fields of view of each eye overlap, and monocular vision outside that overlap. For instance, a forward-facing Tawny Owl (occurring in Europe and Asia) has binocular vision over a 48-degree angle, and monocular vision 76.5 degrees either side of its binocular field. Therefore, this species has a total field of view of 201-degrees in the horizontal plane, 48 degrees of which is forward-facing binocular vision, 153 degrees is peripheral monocular vision, and there is a 159-degree blind spot elsewhere in the plane (Figure 2). Binocular vision provides owls with excellent depth perception and an ability to judge distances accurately.

Collectively, owl species display a broad range of iris colours, including orange, dark brown or black, and yellow. Although not a strict rule, owl species with orange irises are generally active around dawn and dusk (i.e. crepuscular), those with dark brown or black eyes generally hunt at night (i.e. nocturnal) and those with yellow eyes prefer to hunt during the day. There is no evidence that iris colour enhances the vision of owl species under the light regimes of their preferred hunting times. Passarotto *et al*. (2018) suggest that iris coloration is an adaptation to making owls less visible to their prey at times of the day or night when they most often hunt.

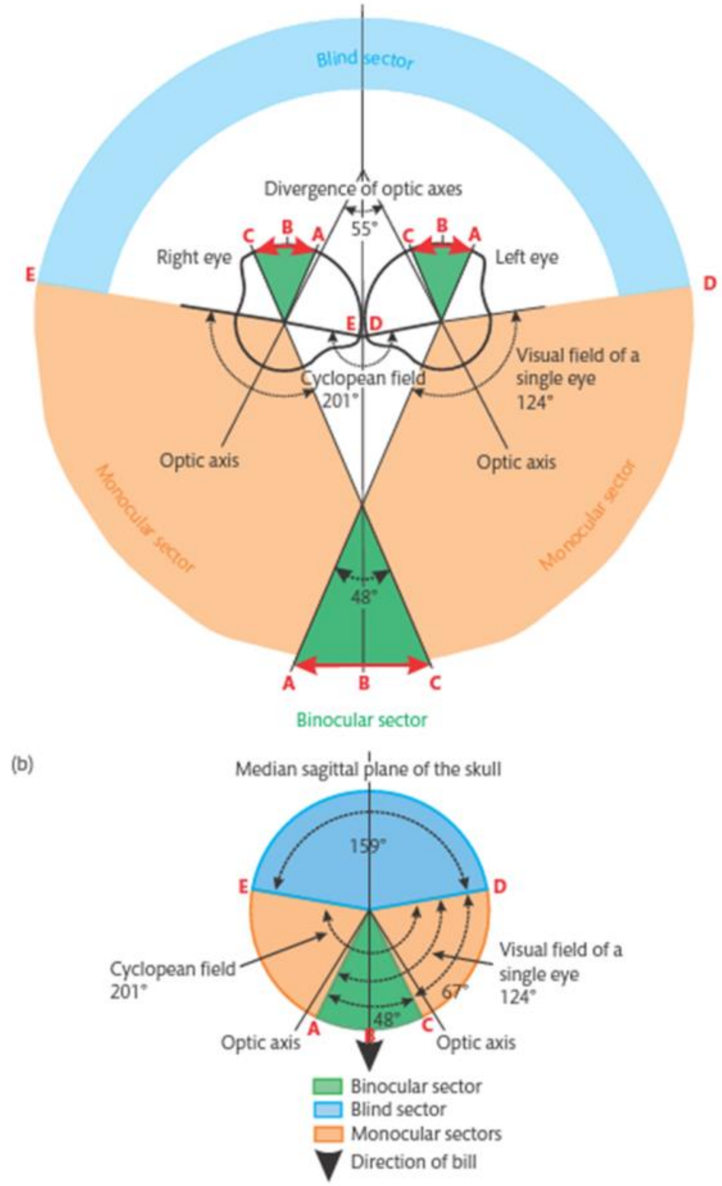


Figure 2. Visual Fields in the Tawny Owl (from Martin 2017).

Owls have an upper and lower eyelid and a nictitating membrane. They close their eyes by lowering the top eyelid, unlike most other bird species which raise the bottom eyelid. The eyes are closed only when the owl is sleeping, dozing off, or when the eyes are in need of additional protection (e.g. when snatching prey, scratching the face with its talon, delivering food to chicks or its mate). For routine blinking, the semi-transparent nictitating membrane sweeps diagonally across the eye, from the inside corner to the outside. The role of this membrane is to keep the eye surface moist and free of particles and pathogens.

2.2 Absolute Sensitivity

Absolute visual sensitivity refers to the smallest amount of light that just elicits visual perception. As far as I am aware, there are no studies of optical physiology in Australian owl species. In a North American study, Dice (1945) showed that Barn Owls, Barred Owls (*Strix varia*) and Long-eared Owls (*Asio otus*) were able to see and approach dead prey directly from a distance of two metres under an illumination as low as 7×10^{-8} lux. The Burrowing Owl (*Athene cunicularia*) was unable to find dead prey regularly under illuminations below 2.4×10^{-6} lux. To place this into context, measured natural illuminances of the night sky range from 1×10^{-4} lux (starlight, overcast moonless night sky) to greater than 0.25 lux (a full moon on a clear night) (Bunning & Moser 1969; Schlyter (2006) (Table 1). Therefore, all four species are capable of detecting and recognising prey close-up under the dimmest natural night light. This is not surprising considering that all four species are mostly nocturnal hunters, the Long-eared Owl in the strictest sense, with the Barn Owl and Barred Owl also known to be crepuscular, and the Burrowing Owl known to also hunt prey anytime on very overcast days.

There are no experimental studies of light intensity tolerances of owls, but light intensity at sunrise or sunset can range from 40 lux under fully overcast conditions to 400 lux on a cloudless day (Table 2). Therefore, crepuscular and diurnal owl species should at least be tolerant of light intensities that are within this range, and probably at higher light intensities if they hunt at other times of the day.

Table 1 **Measured light intensity under a range of night sky conditions (data from Bunning & Moser 1969; Schlyter (2006).**

Illuminance	Example
<1 lux	Moonlight, clear night sky.
0.25 lux	A full moon, clear night sky.
0.01 lux	A quarter moon, clear night sky.
0.002 lux	Starlight, clear moonless night sky, including sky glow.
0.0002 lux	Starlight, clear moonless night sky, excluding sky glow.
0.00014 lux	Venus at brightest, clear night sky.
0.0001 lux	Starlight, overcast moonless night sky.

Table 2 **Measured light intensity under a range of night sky conditions.**
Source: Daylight (Wikipedia) https://en.wikipedia.org/wiki/Daylight

Illuminance	Example
120,000 lux	Brightest sunlight
111,000 lux	Bright sunlight
109,870 lux	AM 1.5 global solar spectrum sunlight (= 1,000.4 W/m^2)
20,000 lux	Shade illuminated by entire clear blue sky, midday
1,000 - 2,000 lux	Typical overcast day, midday
<200 lux	Extreme of thickest storm clouds, midday
400 lux	Sunrise or sunset on a clear day (ambient illumination)
40 lux	Fully overcast, sunset/sunrise
<1 lux	Extreme of thickest storm clouds, sunset/rise

2.3 Visual Acuity

Visual acuity is the clarity or sharpness of vision and is measured as an individual's ability to discern detail (shapes and patterns) under a range of environmental conditions (e.g. different light intensities and distances). In most vertebrates, daylight vision (i.e. photopic vision) is subserved by retinal cones which have high spatial density (in the central fovea) and allow high visual acuity. In low light (i.e. scotopic vision), cones do not have sufficient sensitivity and vision and are subserved by rods. Spatial resolution is then much lower because of the spatial summation of rods. A number of rods merge into a single bipolar cell, which in turn connects to a ganglion cell, and the resulting unit for resolution is large, and acuity small.

Surprisingly, the visual acuity of owls has not been studied widely and a summary of what is known is shown in Figure 3. In general, diurnal terrestrial vertebrates surpass the visual acuity of owls considerably in bright light, largely due to their cone-dominated foveae. However, owls out-perform these species in scotopic conditions (Orlowski *et al.* 2012), as displayed by the Barn Owl and Great Horned Owl (*Bubo virginianus*) in Figure 3. Barn Owls have low acuity and contrast sensitivity; they perform poorly at photopic light levels compared with the other owl species. Under scotopic conditions this is inverted. Orlowksi *et al.* speculate that this is a trade-off by the Barn Owl to maximise absolute sensitivity to light under scotopic conditions.

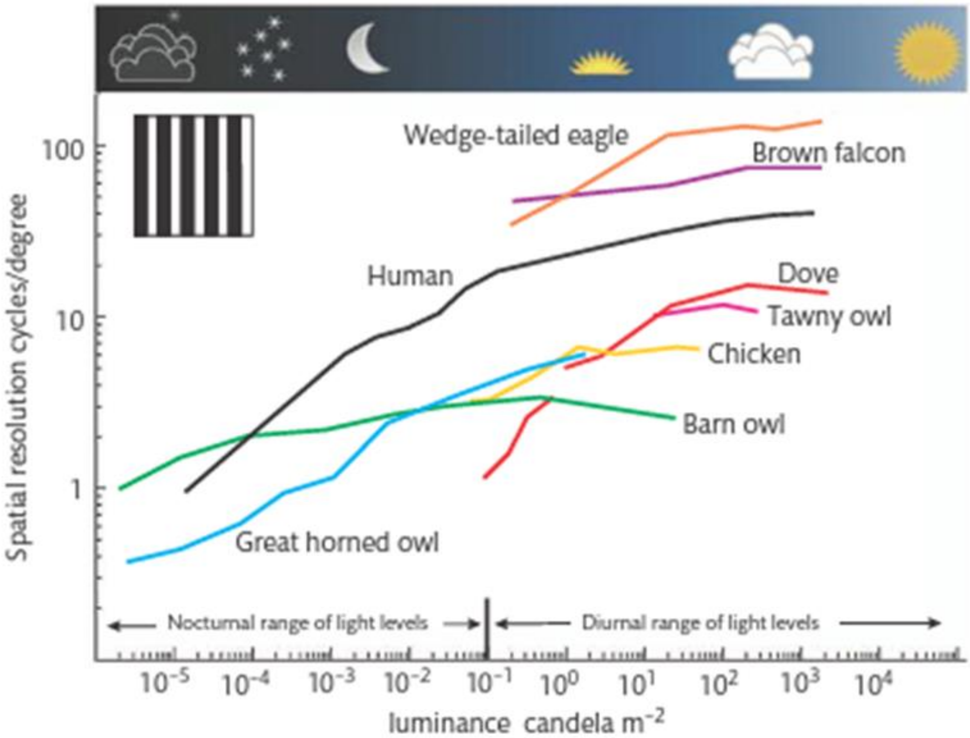


Figure 3 Visual acuity (measured by the visual grating method and expressed as cycles per degree, cpd) in several species as a function of stimulus luminance (candela per square metre, cd/m^2) on logarithmic axes (from Martin 2017).

2.4 Contrast Sensitivity

Contrast sensitivity is the ability to detect subtle differences in shading and patterns. It is important in detecting objects without clear outlines and discriminating objects or details from their background. Contrast sensitivity is particularly important for owls if they only see shades of grey at night, or for recognising a camouflaged prey item in foliage, grass, or on a tree trunk or limb. However, this field of research is in its infancy in relation to owls.

The Barn Owl has a lower peak in contrast sensitivity than humans, macaques, cats, goldfish and kestrels, the peak occurring at lower spatial frequencies than for diurnal raptors such as the kestrel and eagle (Harmening & Wagner 2011) (Figure 4). This supports Orlowski's et al. (2012) idea that the Barn Owl has maximised absolute sensitivity to light at the expense of contrast sensitivity.

2.5 Wavelength Sensitivity

Light reaching the vertebrate eye must pass through ocular media (cornea, lens and humours) before reaching the retina. The transmission of light through the ocular media of owls is reduced significantly at light wavelengths below about 360 nm, the higher wavelength area of the ultraviolet spectrum (Figure 5).

Peak sensitivities of cones in the owl retina are to light wavelengths between 480 nm (blue light) and 570 nm (green light), dropping significantly outside this range. Owls are unlikely to detect wavelengths below 440 nm (violet-blue light) and above 620 nm (orange light) during the day. (Figure 5).

The sensitivity of rods peaks at around 500 nm (blue light), dropping rapidly either side of this peak, and are not sensitive to light outside of the range of 320 nm (larger UV wavelengths) and 620 nm (red light). However, the rods perceive these wavelengths within this light range as shades of grey, rather than colour, in part because they do not contain oil droplets. While the rods show some sensitivity to larger wavelength ultraviolet light, the amount of this light reaching the retina is minimised during ocular media transmission.

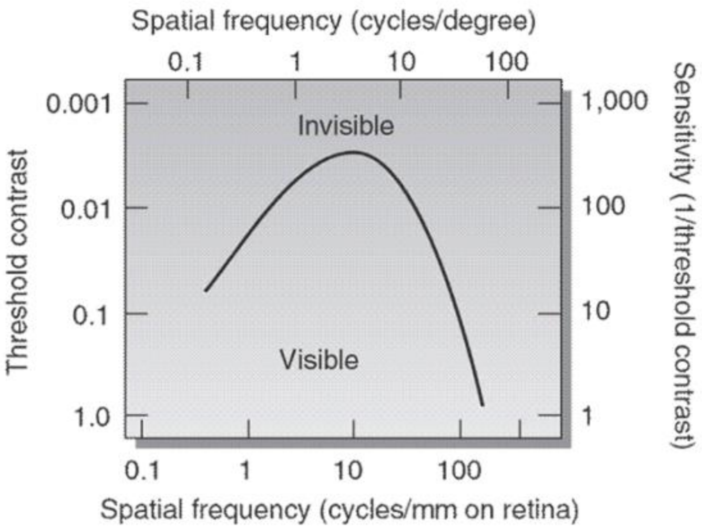
NSW THREATENED OWL SPECIES

3.1 Overview

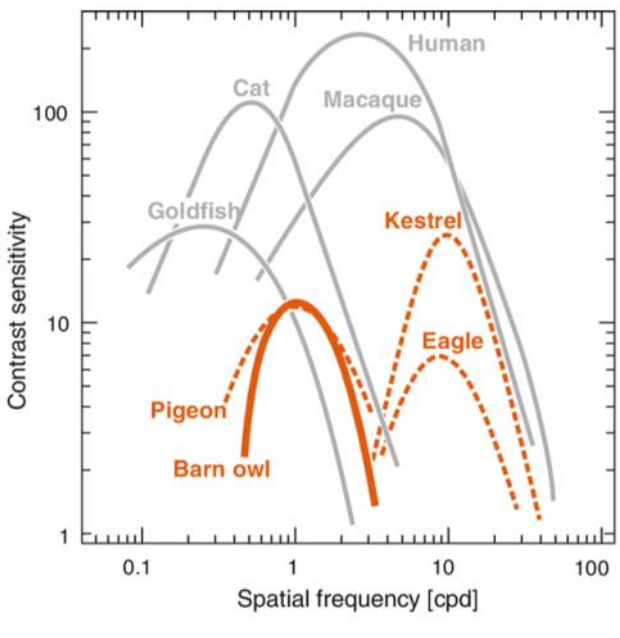
There are five owl species in NSW that are listed as Vulnerable under the schedules of the *Biodiversity Conservation Act, 2016* (BC Act). These are the Powerful Owl (*Ninox strenua*), Barking Owl (*Ninox connivens*) (Family Strigidae), Sooty Owl (*Tyto tenebricosa*), Australian Masked Owl (*Tyto tenebricosa*) and Eastern Grass Owl (*Tyto longimembris*) (Family Tytonidae). The preferred habitats, prey species and hunting times of each species are summarised in Table 3. Two additional owl species that occur in NSW, the Southern Boobook (*Ninox novaeseelandiae*) and Eastern Barn Owl (*Tyto javanica*), though protected native species, are not listed as threatened.

There are no physiological or behavioural studies of the light sensitivities of these owl species. Therefore, in assessing potential impacts of light pollution on them, we have to rely on data for overseas species which have been summarised in Section 2 of the presented article.

While NSW threatened owl species have preferred hunting times, they have also been observed hunting prey outside these periods. Powerful Owls hunt mostly during the evening and dawn light (i.e. are crepuscular), but can extend their hunting into the darkness on moonlit nights (Schodde and Mason 1980). Barking Owls are strongly crepuscular, but are sometimes active during the day (Chisholm 1937) and have been observed hunting opportunistically in strong sunlight (Fleay 1979).



Contrast sensitivity function



Figures 4a & b. The Contrast Sensitivity Function (CSF) Curve

Upper figure: Components of a CSF Curve. *Lower figure:* The CSF curves of the Barn Owl and several other species (Harmening & Wagner 2011).

Spatial frequency expressed as the frequency of a sinusoidal curve (grating) per degree of vision or mm on retina. Threshold contrast is a logarithmic measure of the extent the grating contrasts (stands out from the background of the computer screen). Higher threshold values depict more visible (higher contrasting) stimuli. C*ontrast sensitivity* is plotted logarithmically as the inverse of the threshold contrast. Subject animals are trained to press one of two buttons corresponding to the stimulus orientation.

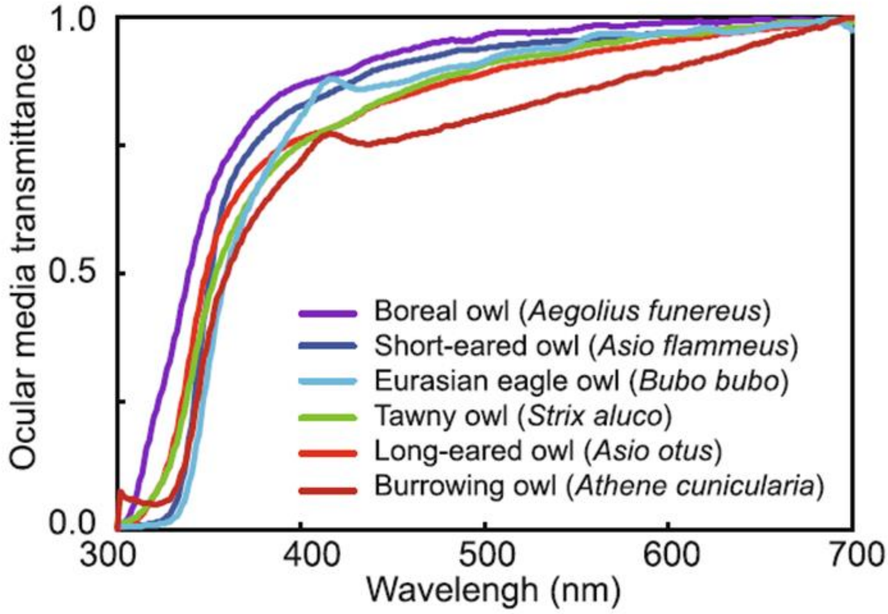


Figure 5. Ocular media transmittance of six species of owl (from Hoglund *et al*. 2019)

Figure 6. Photoreceptor sensitivities of the Tawny Owl, compared with the chicken (from Hoglund *et al*. 2019). A: Normalised spectral absorbance of rod cell (RH1) and cone cells (SWS2, RH2, LWS) visual pigments. B: Ocular media transmittance (OMT) and cone oil droplets of short-, medium- and long-wavelength (S, M and L) single cone cells and double (D) cone cells. C: Expected spectral sensitivity of the rod and cone cells of the owl. D: Chicken photoreceptors, including the violet-sensitive (V) cone cells, which are absent in the owl.

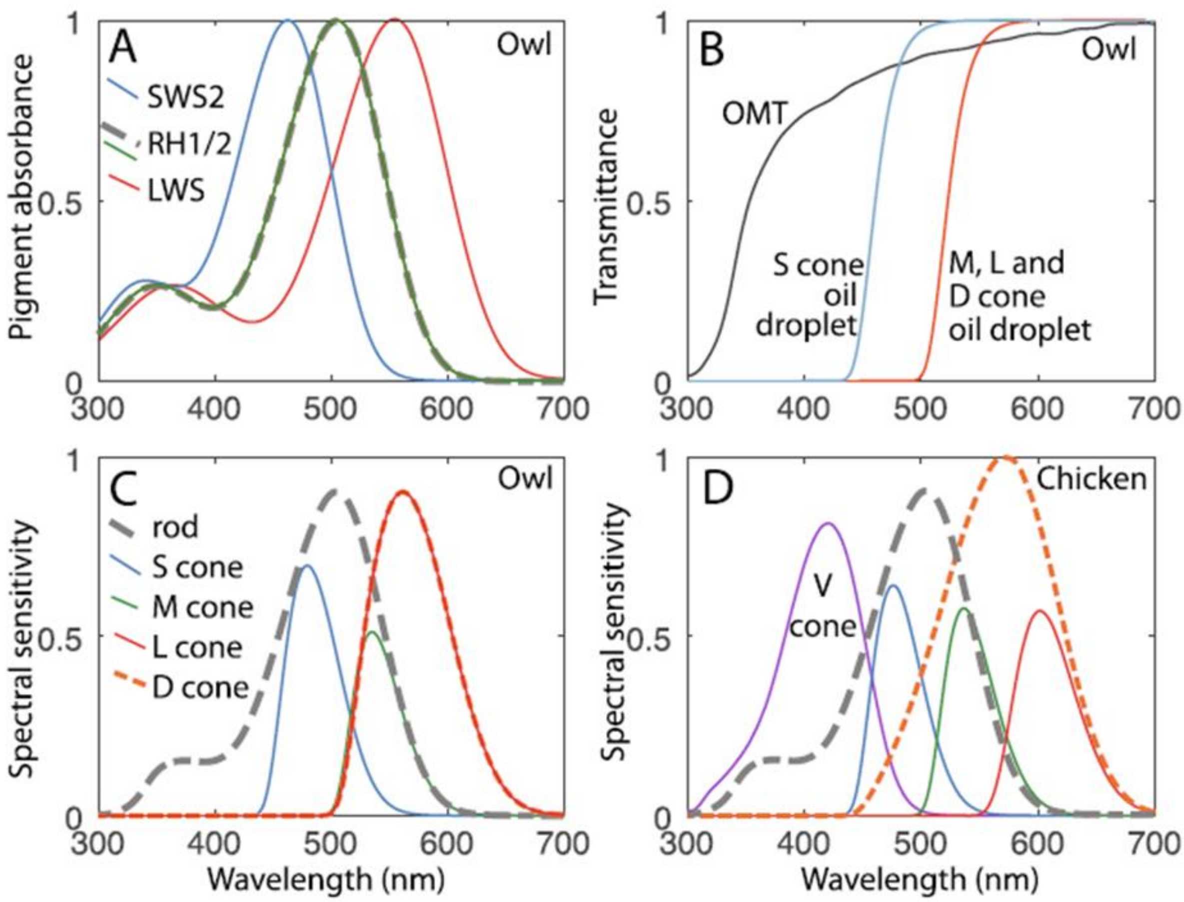


Table 3 Habitat, diet and foraging activities of NSW threatened owl species

Common Name	Scientific Name	NSW Status	Iris Col-	Activity Pattern	Habitat and Diet
Family Strigidae					
Powerful Owl	*Ninox strenua*	Vulnerable	Yellow	Mostly crepuscular, sometimes nocturnal	Inhabits a range of vegetation types, from woodland and open sclerophyll forest to tall open wet forest and rainforest. Requires large tracts of forest or woodland habitat but can occur in fragmented landscapes as well. The species breeds and hunts in open or closed sclerophyll forest or woodlands and occasionally hunts in open habitats. It roosts by day in dense vegetation comprising species such as Turpentine *Syncarpia glomulifera*, Black She-oak *Allocasuarina littoralis*, Blackwood *Acacia melanoxylon*, Rough-barked Apple *Angorphora floribunda*, Cherry Ballart *Exocarpus cupressiformis* and a number of eucalypt species. The main prey items are medium-sized arboreal marsupials, particularly the Greater Glider (*Petauroides volans*), Common Ringtail Possum (*Pseudocheirus peregrinus*) and Sugar Glider (*Petaurus breviceps*). There may be marked regional differences in the prey taken by Powerful Owls. For example, in southern NSW, Common Ringtail Possums make up the bulk of prey in the lowland or coastal habitat. At higher elevations, such as the tableland forests, the Greater Glider may constitute almost all of the prey for a pair of Powerful Owls. Flying foxes are important prey in some areas; birds comprise about 10-50% of the diet depending on the availability of preferred mammals.
Barking Owl	*Ninox connivens*	Vulnerable	Yellow	Strongly crepuscular, sometimes diurnal.	Inhabits woodland and open forest, including fragmented remnants and partly cleared farmland across mainland Australia. It is flexible in its habitat use, and hunting can extend in to closed forest and more open areas. Sometimes able to successfully breed along timbered watercourses in heavily cleared habitats (e.g. western NSW) due to the higher density of prey on these fertile soils. Prefers small arboreal mammals such as Squirrel Gliders (*Petaurus norfolcensis*) and Common Ringtail Possums, but when loss of tree hollows decreases these prey populations the owl becomes more reliant on birds, invertebrates and terrestrial mammals such as rodents and rabbits. Can catch bats and moths on the wing, but typically hunts by sallying from a tall perch.
Family Tytonidae					
Sooty Owl	*Tyto tenebricosa*	Vulnerable	Black	Nocturnal	Occupies the easternmost one-eighth of NSW, occurring on the coast, coastal escarpment and eastern tablelands. Territories are occupied permanently. Occurs in rainforest, including dry rainforest, subtropical and warm temperate rainforest, as well as moist eucalypt forests. Hunts small ground mammals or tree-dwelling mammals such as the Common Ringtail Possum or Sugar Glider (*Petaurus breviceps*).

Table 3 **Habitat, diet and foraging activities of NSW threatened owl species**

Common Name	Scientific Name	NSW Status (BC Act)	Iris Colour	Activity Pattern	Habitat and Diet
Family Tytonidae					
Australian Masked Owl	*Tyto novaehollandiae*	Vulnerable	Black	Nocturnal	Inhabits dry eucalypt forests and woodlands from sea level to 1100 m. Feeds predominantly on tree-dwelling and ground mammals. Common prey include rodents, small dasyurids, possums, bandicoots, rabbits, bats, birds, reptiles and insects.
Eastern Grass Owl	*Tyto longimembris*	Vulnerable	Black	Nocturnal. On rare occasions crepuscular and diurnal	Found in areas of tall grass, including grass tussocks, in swampy areas, grassy plains, swampy heath, and in cane grass or sedges on flood plains. Feeds predominantly on small rodents. Common prey items in some parts of Australia include the Long-haired Rat (*Rattus villosissimus*) and the Cane Rat (*Thryonomys* spp.)

The Sooty and Masked Owls are strictly nocturnal hunters, active soon after dusk (Higgins 1999). Eastern Grass Owls are also nocturnal hunters, becoming active as the sun is setting (Schodde & Mason 1980); when prey is in short supply, grass owls have been observed hunting an hour or so before sunset and through to mid-morning (Estbergs *et al.* 1978). Therefore, it is likely that all five threatened owl species hunt over a broad range of light intensities, the Sooty Owl and perhaps Australian Masked Owl not as broadly as the other three species. On this basis, it is unlikely that the intensity of artificial light from buildings and infrastructure that spill into habitat areas would impact directly and significantly on these species, provided that it is "soft light". I have not seen nocturnal birds in areas directly impacted by light glare or light clustering ("harsh light"), so I suspect they prefer to avoid those lighting conditions.

Significant road mortality of Barn Owls has been recorded in the United Kingdom (Shawyer & Dixon 1999) and Europe (de Jong *et al.* 2018). The UK studies suggest that young Barn Owls dispersing from natal territories are at greatest risk of being killed by traffic. The European study (in the Netherlands) suggest that road mortality is highest when Barn Owls forage for rodents on or at the sides of roads when prey is in short supply in agricultural fields. Barn Owls can fly low over roads when dispersing or carrying prey, and may be slow in taking flight when startled by oncoming traffic, increasing their risk of collision with a vehicle. But the glare from the headlights of an approaching vehicle may disorientate an owl which could result in it flying into the vehicle's path. There is significant road mortality of Powerful Owls in Sydney, particular in the North Shore Area (Dr Beth Mott, BirdLife Australia, *pers. comm*.); it is possible that individuals of this species are killed by traffic after being startled by the glare of headlights while they have been scavenging possum roadkill.

Prolonged exposure to short-wavelength light (ultraviolet, violet and blue light) can physically damage photoreceptors in the retina, as well impact on an animal's circadian rhythms to the 24-hour light/dark cycle (see Ambrose 2020). Nocturnal animals that rely on scotopic vision are particularly vulnerable to the impacts of short wavelength light, although, as discussed in Section 2 of the present article, the amount of ultraviolet light reaching the owl retina is minimised by the ocular media. Of particular concern is artificial light emitting blue wavelengths, because the photoreceptors display peak sensitivities in the blue-green part of the spectrum under scotopic conditions. Therefore, it is important to use lights with reduced or filtered-out blue, violet and ultraviolet wavelengths, in conformity with the management principles of the Draft National Light Pollution Guidelines for Wildlife (DEE 2019).

Australian owls are known to collide with glass panes and glass balustrades, especially buildings that abut or intrude into owl habitat. Unpublished BirdLife Australia data indicate that significant numbers of Powerful Owls in the Greater Sydney Area have been killed when colliding with glass panes (Dr Beth Mott, *pers. comm*.). This is likely to be the result of the glass being invisible to owls in complete darkness or when internal lighting provides the impression that there is an unimpeded flight path into the building. There is also a possibility that outdoor lights around a building create enough glare and/or light clutter to disorientate an owl in flight, causing it to fly into a glass barrier. These types of collisions can be avoided or minimised by developments being located outside important owl habitat; if that cannot be avoided, then outdoor lighting should be minimised in terms of brightness, area of light spillage, and times and duration of use. Where possible, internal window coverings (e.g. curtains or blinds) should be used to reduce internal light spillage to outside areas and to make glass windows more visible. The visibility of glass to birds can also be maximised through etching or the incorporation of materials in the manufacture of the glass to reflect low intensity light that is visible to birds at night.

When assessing potential light pollution impacts on owls, it is also important to consider these impacts on their prey species. If light sources significantly affect the spatial distribution and abundance of local sources of prey, then could that in turn significantly impact on the food availability and breeding success of resident owls? I have been involved in a number of Land and Environment Court of NSW cases over the last few years where this has been an issue in relation to Powerful Owls and their prey. It is a matter of identifying local prey species, documenting or predicting their abundances as accurately as possible, their home ranges, the proportion of their local habitat that would be impacted by light pollution, artificial light intensities, the sensitivities of prey species to light pollution, and their probable short- and longer-term behavioural and physiological responses. If localised prey availability (or the localised foraging success of the owls) is likely be compromised by the proposed development, would that impact significantly on the overall availability of food sources for resident owls during and outside the breeding periods? Insufficient data are often collected to answer these questions precisely, but a knowledgeable ecological consultant should be able to make scientifically-informed predictions with confidence.

In conclusion, the consideration of light pollution impacts on owls is complex, involving many factors. It is virtually an unknown science in Australia, and most of what we know about the topic is based on the results of overseas studies. Collectively, Australian owls occupy similar ecological niches to those few owl species that have been studied overseas, and there is no reason to believe that their responses to ambient light would significantly differ. But you never know! So, if there is anyone who would like to conduct research into sensitivities of Australian owls to ambient light, it is an open ball park.

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NOTES ON MICROSCOPE PHOTOGRAPHY TO AID BOTANICAL IDENTIFICATION

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For the last couple of years, I have been taking macro-photographic stills of NSW coast and tableland native Cyperaceae, Restionaceae, Poaceae and some Orchidaceae genera (eg. *Thelymitra* and *Caladenia spp*.) with a view to creating a colour macro photo database or reference library of key diagnostic reproductive and vegetative parts for these difficult to ID families. Ultimately, I plan to develop an app or e-book of the reference images which can be used in conjunction with existing botanical keys to aid identification. It is my hope that this project will provide a useful, modern 'supplement' to the line drawings of florets that are provided on PlantNet and VicFlora websites as well as those in botanical reference texts (eg. Flora of NSW, Grasses of NSW, Van Klaphake guidebooks) and hopefully add to the already impressive collection of Acacia, Eucalypt and Rainforest apps. The project started due to my frustration of the almost complete lack of reference macro images of grass and sedge spikelets and florets on the internet or as modern apps (try to search them out and you will see what I mean).

I typically use my high resolution DSLR with an adaptor which attaches to the trinocular port on my stereo-zoom microscope to take the images. In recent months, however, I have been using my smartphone to take the macro images using a smartphone adaptor which attaches directly to one of my two front microscope eyepieces. The resultant images taken from the smartphone are generally not on par with the DSLR and may not be of a quality needed for an app or e-book (see photos below). Nevertheless, the convenience of being able to take images with my smartphone on the front eyepiece compared with having to fit my bulkier and heavier DSLR onto the less user-friendly rear trinocular port, has yielded far more images being taken of plants that I dissect and identify with the microscope, and has become part of my normal botanical ID workflow. Since it is time consuming (and not that easy) to carefully dissect and ID tiny spikelets, it makes sense for me to include the macro images in my workflow rather than make it a separate process post-project when I may have some spare time (to do it all again!).

Okay, so what exactly am I taking macro stills images of, you ask?

1. Ligules and leaf sheaths;
2. Spikelet;
3. Within each spikelet, lower sterile glumes, fertile glumes, lemma, lemma lobes (Rytidosperma), palea, awns, callus (web in Poa spp.);
4. Inner and outer tepals (Juncaceae, Restionaceae);
5. Nut/capsule (Cyperacea, Juncaceae, Restionaceae);
6. Utricle and stigma (Carex spp.); and
7. Stamens.

As an identifications botanist, being able to clearly see and compare colour macro images of, for example, utricles and stigmas of different *Carex* species, hair arrangements on the lemmas of *Poa and Rytidoseprma spp*., shape and length of lateral lobes of *Rytidosperma* lemmas, hyaline margins of tepals and size of inner and outer tepals relative to the nut/capsule, as well as the size, shape, colour and venation of glumes, helps greatly in successfully keying out taxa, or at least verifying that you have successfully keyed out the correct taxon, in my experience.

The improvement in smartphone cameras, the availability of smartphone camera microscope eyepiece adaptors, trinocular ports and reasonably priced mid- to high-resolution DSLRs has made it possible to incorporate taking good quality macro images as a typical part of my microscope ID workflow. Software such as Adobe Lightroom has also made it relatively easy to edit and database my stills images. I generally add some sharpening, noise reduction, exposure and clarity refinement as well as highlights and shadows refinement and cropping. Where I have an image of, for example, a *Juncus* or *Lepyrodia* tepal/capsule, which is round in shape and not on a level plane, it is often not possible to have all of the floret parts in sharp focus due to the very shallow depth of field of macro photography. As such, I am trying to adopt methods such as photo stacking, photo bracketing and focus peaking to achieve better results. Using a glass slide to hold the floret in place and to try and get most floral parts on a relatively flat plane is also helpful to some extent.

Some of my smartphone images below (a work in progress)

Utricle/stigma + glume of *Carex maculata*

Utricle and stigma of *Carex appressa*

Pedicel + Spikelet of *Schoenus melanostachys*

Black/red brown leaf sheath + hairs of *S.melanostachys*

Grass spikelet + lemma of *Arundinella nepalensis*

Bisexual glume of *S. melanostachys* with 3 stamens

Tepals and capsule of *Lepyrodia scariosa*

Glume + tepals with 2 stamens of *Eury-chorda complanata*

Contributions to the Newsletter, Volume 46

Contributions to the next newsletter should be forwarded to the administration assistant Amy Rowles admin@ecansw.org.au by the **28th of February 2021.**

- Articles may be emailed in WORD, with photos included or referenced in an attached file as a jpg.
- Please keep file size to a minimum, however there is no limit on article size (within reason)
- Ensure all photos are owned by you, or you have permission from the owner
- Ensure that any data presented is yours and you have permission from your client to refer to a specific site (if not please generalise the location).
- All articles will be reviewed by the editorial committee, and we reserve the right to request amendments to submitted articles or not to publish.
- Please avoid inflammatory comments about specific persons or entity

The following contributions are welcome and encouraged:

◊ Relevant articles
◊ Anecdotal ecological observations
◊ Hints and information
◊ Upcoming events
◊ Recent literature
◊ New publications (including reviews)
◊ Photographs

STRATEGIC PLANNING FOR BIODIVERSITY IN CITIES AND TOWNS: A NEED FOR A MORE PROACTIVE ROLE BY ECOLOGICAL CONSULTANTS.

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1. INTRODUCTION

Cities and towns are dominated by human-built structures and activities (e.g. buildings and infrastructure, vehicles, impermeable surfaces, landscaped parks), but they are functioning ecosystems that possess many of the same components (plants, animals, water, soil etc.) and processes (nutrient and water cycles) as more natural areas (McDonnell & Pickett 1993; Grimm *et al*. 2003).

Globally, urban environments are relatively rich in biodiversity, with at least 20% of the world's bird species and 5% of plant species recorded in cities (Aronson *et al*. 2014). In Australia, cities are also hotspots for threatened species, with about 30% of species listed as threatened under the *Environment and Biodiversity Conservation Act, 1999* (EPBC Act) occurring in them (Ives *et al*. 2016). Moreover, remnant habitat in the urban fringe (i.e. areas proximal to Australian cities) contain 40% of nationally-listed threatened ecological communities (Newton *et al*. 2001) and more than 50% of nationally-listed threatened species (Yencken & Wilkinson 2000). Urban areas are not only important for resident species, but also for more mobile species that use them as temporary or permanent refuge areas in response to habitat clearance and extreme weather events (e.g. drought, floods, cyclones). Habitat islands and corridors in cities and towns are often critical "stepping stones" for dispersing, migratory and nomadic species. Habitat patch area and their connectivity have the strongest positive impacts on urban biodiversity, complemented by vegetation structure (Beninde *et al*. 2015). Therefore, it is essential that important habitat for biodiversity in cities and town is protected and enhanced in quality.

To design biodiversity-sensitive urban landscapes, and to prioritise biodiversity considerations against other social and economic factors, policy-makers, planners, property developers, environmental impact assessors, and the broader community need information on what urban landscape and habitat features are important for biodiversity (Stagoll *et al*. 2010; Ikin *et al*. 2012). However, all too often, expert ecological advice is an afterthought in the strategic planning process, and ecological consultants are either brought into the process in the final stages of planning, or not at all. Moreover, ongoing biodiversity monitoring and longer-term reviews of biodiversity and habitat management plans, either at an individual site level or in more strategic assessments of town and city councils, can only be conducted by specialist ecologists. While these latter actions are beginning to emerge, they are still rare and are usually adopted only by larger, better-resourced city councils. Therefore, there is a critical role for ecological consultants to not only provide these services, but actively promote the need for them. This essay identifies key ecological factors and actions that are essential in protecting and enhancing urban biodiversity, and the roles that ecological consultants should play in their promotion and implementation.

2. PLANNING FOR BIODIVERSITY

2.1 Overview

iRapid urban expansion and associated anthropogenic processes are impacting heavily on ecological processes, and are significant factors in both current and predicted ecological community, species and population extinctions (McDonald *et al.* 2008). Development at the urban fringe has ecological impacts that extend into the surrounding landscapes (Renjifo 2002; Brearley *et al.* 2010), which can impact significantly on species and ecosystems (Parris & Schneider 2008; Threlfall *et al.* 2013). Goddard *et al.* (2010) identify the urban impacts that contribute to biodiversity decline, shown in Table 1 of this essay. Parris *et al.* (2018) identify seven main strategies for reducing these impacts. These are:

- protection of remaining ecological assets and habitats;
- connectivity of biological populations and habitats;
- construction of diverse and complex habitats to attract or retain biodiversity;
- maintenance of nutrient and water cycles that mimic natural flows;
- maintenance of interactions within and between ecosystem components;
- benevolence of urban forms to reduce negative impacts on biodiversity; and
- novel ecological communities and ecosystems that are characterised by the presence of new and exotic species.

Nilon *et al.* (2017) summarises how these strategies can be incorporated into a city's overall biodiversity strategy plan (Table 2). The strategies are characterised into biodiversity goals (biodiversity conservation objectives) and ecosystem-services (planning objectives that would benefit urban biodiversity directly). Nilon *et al.* found that the most common ecological-services addressed globally in urban biodiversity strategy plans were air and water quality, carbon sequestration, urban heat-island amelioration, urban agriculture, and cultural services (e.g. recreation or fostering a "sense of place). Equally important is access to baseline data to determine the biodiversity status, and availability and condition of habitats in the town or city prior to the design and implementation of a biodiversity strategy plan. The plan also needs to identify quantifiable outcomes for comparison with the baseline data, so that its degree of success in protecting and enhancing the city's biodiversity can be assessed readily and regularly.

Table 1 Impacts of urbanisation on habitat and resultant biological effects (from Goddard *et al.* 2010)

Impact of Urbanisation on Habitat	Biological Effects	Reference
Habitat loss, fragmentation and disturbance.	Reduced species richness and evenness resulting in biotic homogenisation. Peaked species richness at intermediate levels of urbanisation, particularly for birds and plants.	McKinney (2008)
Introduction of new species for human landscaping.	Domination of floras by exotic species, causing increased species richness relative to rural areas, but decreased native plant diversity. Invasion of species to surrounding semi-natural habitats.	Niinemets & Peneulas (2008); Wania *et al.* (2006).
Increased air temperatures and altered atmospheric chemistry (i.e. elevated CO_2, NO_x, aerosols, metals and ozone.	Altered nutrient cycling, primary production and plant growth.	Kaye *et al.* (2006); Shen *et al.* (2008).
Increase in impervious surfaces, which the hydrology of urban watersheds.	Decreased biodiversity, high nutrient loadings and elevated primary production produce an "urban stream syndrome".	Grimm *et al.* (2008)
Altered productivity, competition and predation.	Shifts in trophic structure and food-web dynamics.	Shochat *et al.* (2006)
Altered environmental conditions (e.g. natural/artificial lighting regimes, increased ambient sound).	Local adaptation and evolution caused by behavioural, morphological and genetic responses to novel selective pressures (e.g. noise necessitating changes in bird song).	Partecke & Gwinner (2007); Slabbekoorn & Ripmeester (2008)

Table 2 Attributes that should be incorporated into a city's biodiversity strategy plan (from Nilon *et al.* 2017).

Attribute	Description	References
Baseline data.	Baseline species and habitat data from within the city.	Hermy & Cornelis (2000); Cilliers *et al.* (2004); Farina-Marques *et al.* (2011); Rebelo *et al.* (2011); Bekessy *et al.* (2012); Holmes *et al.* (2012)
Biodiversity goals.	Does the plan have specific and/or general biodiversity goals (i.e. protect biodiversity, ecology, specific species, habitats, natural resources, genetic resources)?	
	Specific reference to corridors, increasing connectivity for ecological purposes, or creating a green network.	Mortberg *et al.* (2007); Beninde *et al.* (2015)
	Identification of target species or populations in need of protection and enhancement in the city.	Rebelo *et al.* (2011); Holmes *et al.* (2012);
	Identification and conservation, restoration, maintenance, or management of forests, grasslands, wetlands, woodlands and open space.	Margules & Pressy (2000); Rebelo *et al.* (2011); Saetersdal & Gjerde (2011); Holmes *et al.* (2012); Lindenmayer *et al.* (2014); Beninde *et al.* (2015).
	Formal and informal public education about biodiversity conservation.	Miller & Hobbs (2002); Dearborn & Kark (2009); Goddard *et al.* (2010); Holmes *et al.* (2012); Kabish (2015).
	Encouragement of involvement in biodiversity conservation by volunteer groups, non-governmental organisations, citizen scientists and the broader community.	Savard *et al.* (2000); Miller & Hobbs (2002); Dearborn & Kark (2009); Goddard *et al.* (2010); Holmes *et al.* (2012).
	Species and habitat monitoring, ecological research and adaptive management.	Noss (1990); Turner *et al.* (2003).
	Management and reduction of invasive species.	Pysek (1998); von der Lippe & Kowarik (2008); Aronson & Handel (2011).
	Habitat construction, e.g. bioswales, green roofs, green streets, gardens, wetlands and parkland.	Lyle (1997); Margolis & Robinson (2007); Oberndorfer *et al.* (2007); Ignatieva *et al.* (2011); MacIvor & Lundholm (2011); Rottle & Yocom (2011); Chiquet *et al.* (2013); Braaker *et al.* (2014).

Attribute	Description	References
Desired biodiversity outcomes.	Achieving quantitative targets for increasing populations of species identified by the conservation plan. Achieving quantitative targets for increasing habitat area identified by the conservation plan. Achieving quantitative targets for particular taxa: 10 groups – plants, mammals, birds, reptiles, amphibians, fish, molluscs, butterflies, other arthropods, fungi – identified for conservation. Achieving quantitative targets for decreasing the number and area of occupancy of invasive species. Achieving quantitative targets for increasing the number and area of critical biodiversity habitats.	Berke & Godschalk (2009).
Ecosystem-services goals	Does the plan have specific and/or general ecosystem goals?	
	Identification of measures and targets for increasing water quality and flood retention, including stormwater, freshwater wetlands, lakes, saltmarshes, floodplains and riparian areas.	Cardinale (2011); Balvanera *et al.* (2013); Ahern *et al*. (2014).
	Identification of tree cover targets for air pollution removal.	Nowak *et al.* (2006); Manes *et al.* (2012); Ahern *et al.* (2014).
	Required tree-planting efforts and vegetation conservation for carbon-storage and sequestration. Required tree-planting efforts and vegetation community conservation for climate amelioration or cooling of urban heat islands.	Balvanera *et al.* (2013); McPherson *et al.* (2008); Pincetl *et al.* (2013); Ahern *et al.* (2014).
	Identification of areas required for food production, urban gardens, or urban agriculture.	Ahern *et al.* (2014); Bernstein (2014); Potter & LeBuhn (2015).
	Identification of public places that are specifically for "sense of place", education, stewardship or education, as well as for biodiversity and habitat protection and enhancement.	Gill *et al.* (2009); Pickett *et al.* (2011); Ahern *et al*. (2014).
Desired ecosystem-services outcomes.	Achieving quantitative targets for the reduction in water pollutants or increase in wetland habitat. Achieving quantitative targets for the reduction of air pollutants by planting efforts or other conservation measures. Achieving quantitative targets for increasing the number of trees or biomass for carbon storage and sequestration processes. Achieving quantitative targets for reducing urban heat island effects via tree planting, the conservation of remnant vegetation, or other conservation efforts. Achieving quantitative targets for food production, urban gardens and parkland, and urban agriculture. Achieving quantitative targets for biodiversity conservation, habitats or ecological communities for sense of place, education and stewardship.	Berke & Godschalk (2009).

2.2 Protection of Ecological Assets and Habitat

The amount of urban green space in cities is an important determinant of biodiversity (Aronson *et al*. 2014; Beninde *et al.* 2015). It is difficult to recreate entire ecological communities or ecosystems once they are lost, and protection of existing biodiverse areas is more effective than attempting to recreate them (Jackson & Hobbs 2009). Therefore, it is important to identify and protect areas of high biodiversity in and around cities (McKinney 2002).

Care should be taken in selecting habitat areas to protect because they could potentially act as an ecological trap. This occurs when individuals select low-quality habitat over other available habitat such that the resultant reproductive and survival rate of the population or sub-population cannot be sustained (Donovan & Thompson 2001). Ecological traps can be created by urban features such as buildings, roads and light pollution, and can contribute significantly to the extinction of local populations of a broad range of taxa (Robertson *et al*. 2013). For instance, urban areas can create ecological traps for breeding songbirds by increasing nest predation rates (Bonnington *et al*. 2015), and urban raptors by providing nesting habitat, but insufficient food (Sumasgutner *et al*. 2018). Many ecological traps act as ecological sinks by trapping individuals that have dispersed from neighbouring or distant non-urban habitats, e.g. dispersing juvenile birds (Withey & Marzluff 2005), fish and tadpoles that are transported to stormwater basins by urban runoff (McCarthey & Lathrop 2011) and moth species that are attracted to artificial light (Bates *et al*. 2014; Warrant *et al*. 2016).

Habitat areas that should be retained include patches of remnant vegetation, wetlands, drainage lines, rocky outcrops, and larger green spaces containing a variety of habitat types with both amenity and biodiversity value (Bekessy *et al*. 2012; Threlfall *et al*. 2015).

It is also essential to minimise impacts on retained green spaces from neighbouring urban development (e.g. artificial light and noise pollution, weed and other exotic plant invasion, and stormwater runoff). Therefore, urban planning should consider carefully the impacts of encroachment, housing density and urban-related disturbances on green spaces (Ikin *et al*. 2015). Core habitat areas can be retained and impacts minimised by protecting them outside cities and towns. If core habitat occurs within urban boundaries, then intensive development adjacent to it should be avoided (Palmer *et al.* 2008; Ikin *et al*. 2013b; Villaseñor *et al.* 2014).

Patch size and habitat quality are important factors to consider when choosing which green spaces to retain for biodiversity purposes (Evans *et al*. 2009, Shwartz *et al.* 2013; Williams & Winfree 2013; Matthies *et al.* 2017). For instance, at least 10-35 ha of continuous green space are required to support most urbanised bird populations (Fernandez-Juricic & Jokimaki 2001; Chamberlain *et al*. 2007). However, most city parks fall below this size range (Jokimaki 1999), and even small urban green spaces can support considerable biodiversity provided that there is sufficient habitat quality (Holtmann *et al.* 2017; Matthies *et al.* 2017). While most studies have focused on the relationship between patch size and bird species richness, minimum patch size thresholds for other animal and plant taxa are not well understood. This is problematic because different taxa operate at different ecological scales, adding to the difficulty of deciding which habitat patches to protect and manage. For instance, bat species that normally forage in densely-vegetated habitats are uncommon in urban areas, but those that forage in open habitats are likely to be more tolerant of greater housing density (Threlfall *et al*. 2011; Luck *et al*. 2013).

Retained green spaces should contain foraging and nesting habitat for a broad range of species. Ikin *et al*. (2013b) found that uncommon suburban bird species are more abundant in areas with a complex vegetation structure, and Villaseñor *et al.* (2015) recorded small native mammals in areas containing extensive understorey vegetation. However, Le Roux *et al.* (2014a) state that many urban green spaces are unable to support a lot of native fauna species because of the reduced availability or absence of live and dead trees, seedlings, hollows, logs, and native ground and mid-storey vegetation.

2.3 Connectivity

Habitat corridors in urban areas are essential for maintaining or re-establishing connectivity between key habitat areas, and are practical conservation measures that ameliorate habitat loss and fragmentation effects (Bennet 1990a). They allow the movement of animals and the propagules of fungi and plants (spores, pollen and seeds) across the urban landscape (Soule & Gilpin 1991; Kong *et al*. 2010; Lapoint *et al.* 2015). These movements are important for the maintenance of genetic diversity and the long-term persistence of populations and diverse ecological communities (Saunders *et al*. 1991; Epps *et al*. 2005). The movement of individuals between discrete areas of habitat can also help support viable metapopulations (groups of populations separated in space, but linked by dispersal), rescue declining populations and aid recolonisation of vacant habitat (Delaney *et al*. 2010; Ahern 2013; Vergnes *et al*. 2013).

Connery (2009) lists four main spatial design goals for connecting key biodiversity habitat areas within and adjacent to cities and towns:

- Retain and protect large patches of remnant vegetation that support entire populations of plants and animals and associated ecological processes.
- Maximize the width and function of riparian corridors as the "preferred corridor for wildlife movement".
- Retain and protect connections/linkages between large patches of remnant vegetation, using corridors and stepping stones. These linkages are essential for daily movements, seasonal migrations, dispersal, habitat connectivity and species persistence.
- Where possible, public spaces should contain intact vegetation to facilitate the movement of species within and through urban areas to adjacent corridors and habitat patches.

Vegetated corridors that comprise a mosaic of different habitats are considered more likely to contain the necessary food, shelter and nesting resources for fauna. Seasonal resource requirements are essential for survival and may only be found between a range of habitats at different altitudes and geographic variations (Recher 1993). Therefore, corridors that link patches over the entire ecological gradient from ridge to gully would conserve more species, especially those that have large home ranges and changing seasonal requirements (Lindenmayer *et al*. 1994).

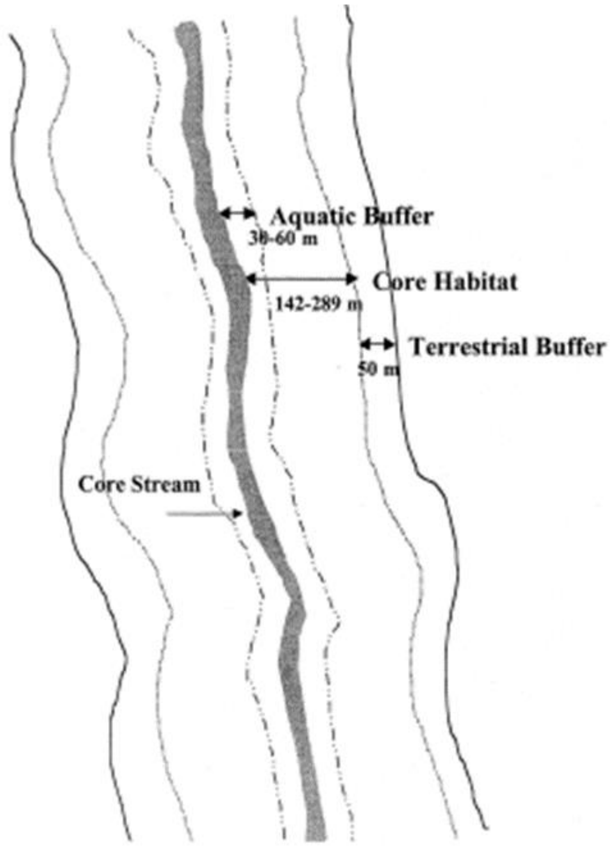
The quality of the habitat within the corridor is important. Some fauna reluctantly utilise corridors of low quality, such as areas invaded by weeds or subject to frequent fires, or due to a reduction in the availability of essential resources (such as feeding, shelter, roosting and breeding sites).

The size of the corridor is also important. For example, corridors with mature trees, but with little or no understorey may afford good habitat links for birds, bats and some arboreal fauna, but not for ground-dwelling fauna.

Corridors that are 200 or more metres in width tend to facilitate the movement of all fauna by providing at least some core interior habitat that is not affected by edge environments (Lindenmayer 1994). Corridors between 80 and 200 m width tend to be effective at moving many fauna, including some fauna that do not tolerate urban disturbance and fragmentation (such as Sugar Gliders and some forest-dependent birds) (Bennett 1990b; Claridge & Lindenmayer 1994; Saunders & de Rebeira 1991; Catterall *et al.* 1991; Bentley & Catterall 1997). Corridors less than 30 m in width tend to effective only for servicing the most tolerant of urban fauna (for instance, Brushtail Possums, Bush Rats, common urban birds (Bennett 1990a,b; Lindenmayer 1994; Catterall *et al*. 1991; Bentley &

Catterall 1997) and small animals such as invertebrates, reptiles and amphibians (Lynch & Catterall 1999; Catterall *et al*. 2007). Murcia (1995) and Semlitsch & Bodie (2003) highlight the importance of providing an outer zone that is at least 50 m in width on either side of the corridor that buffers it from edge effects imposed by surrounding land-use (Figure 1).

Figure 1 Proposed zones of frog and reptile habitat protection along riparian corridors (from Semlitsch & Bodie 2003)



Core stream: aquatic habitat.

Aquatic Buffer: a terrestrial zone immediately adjacent to the aquatic habitat, which is restricted from use and designed to buffer the core aquatic habitat and protect water resources.

Core Habitat: a terrestrial habitat zone used by frogs and amphibians to forage, disperse, aestivate or hibernate, and exhibit breeding behaviours.

Terrestrial Buffer: a terrestrial zone for buffering the core terrestrial habitat from edge effects imposed by surrounding land-use.

Gaps between vegetation links should be narrow. Catterall *et al*. (1991) found that gaps greater than 15 m in width represent a significant barrier to the movement of forest dependent birds. Barnett (1978) found that a small mammal's ability to cross an unvegetated gap was inversely proportional to the size of the gap. Lynch & Saunders (1991) found that the existence of a well-developed understorey was the single most important vegetation-related factor in corridor use by small bushland birds (Sewell & Catterall 1998).

Ikin *et al*. (2013a) found that for birds that are able to fly easily between green space habitats, increasing the total amount of green space area is more important than large or well-connected patches. This was true even for woodland-dependent, insectivorous and hollow-nesting bird species. This green-spacing strategy is also beneficial for amphibian, reptile and small mammal assemblages (Garden *et al.* 2010; Hamer & Parris 2010).

2.4 Construction of Diverse and Complex Habitats

a) General Concepts

Urban development not only results in extensive loss of habitat, but also a reduction in habitat complexity across the landscape (Paul & Meyer 2001; Alberti *et al.* 2003; Grimm *et al*. 2008; Luck & Smallbone 2011). Therefore, it is essential to construct new habitats which have the structural complexity and that provide resources aimed at promoting and sustaining urban species richness and diversity (Tews *et al*. 2004). Urban planners and landscape architects are often the only professionals involved in the placement and design of constructed habitats and, understandably, most lack the ecological knowledge and foresight to create habitats that are of real value to locally-native biodiversity. A common outcome of insufficient ecological advice and monitoring is the creation of habitats that contain a large number of non-native species and which have limited value for, and often impacting negatively on, locally-native biodiversity. Therefore, it is essential for ecological consultants and researchers to play a significant role in habitat design, construction, ecological management and monitoring their effectiveness. Ultimately, though, conserving, designing and management of urban green spaces have to be a balance between the public's needs and expectations, and the ecological requirements for protection and enhancing local biodiversity (Aronson et al. 2017).

Ikin *et al.* (2015) suggest that the bushfire risk in newly-constructed habitats, and a public sense of "untidiness" can be minimised by the creation of "habitat islands" around existing habitat structures, e.g. rocky outcrops, logs or large dead trees. This approach has been relatively successful in providing additional habitat for insectivorous bats in riparian zones (see Threlfall *et al*. 2012a,b). Replacement of weedy understorey plants with native species helps provide shrub habitat for many small bird species (Kath *et al*. 2009; Stagoll *et al.* 2010). Habitat islands, which are potential stepping-stones for dispersing or mobile urban-tolerant species, can also be created in urban streets, including on roundabouts (Figure 2).

Figure 2 **Landscaped urban roundabout with canopy, understorey and a diverse shrub layer, City of Melbourne**
Source: Haptic Pathways https://dcp-ecp.com/projects/haptic-pathways

Parsons *et al.* (2006) and Davis & Wilcox (2013) state that flowering native cultivars in constructed habitats in Australia can lead to an overabundance of aggressive honeyeaters, which can exclude smaller bird species. Conversely, low-nectar producing native species help minimise these aggressive interactions (Kath *et al.* 2009). Therefore, Ikin *et al.* (2015) recommend the use of these latter plant species over cultivars in new habitat areas, including gardens.

Large eucalypt trees in large small urban parks in Australia increase the richness and abundances of bird species, and the probability that they will nest there (Stagoll *et al.* 2012). Le Roux *et al.* (2015) also found that the addition of a single large tree to a suburb or a park will attract as many bird species and individuals as would many small and medium-sized trees. Conversely, the loss of a single large tree as habitat for fauna species in an urban location is not adequately offset by planting many younger trees (Le Roux *et al*. 2014b). Ikin *et al*. (2015) propose the following measures for managing old trees in new developments:

- □ Design new developments to incorporate existing locally-native vegetation into planned green space areas. Where possible, retain and enhance trees and understorey vegetation cover.
- □ Retain large old trees by designing green space areas around where they occur and improve their protection through the implementation of tree preservation orders.
- □ Increase the maximum standing life of trees so that they reach full habitat potential.
- □ Protect regenerating areas, and increase the number of seedlings planted elsewhere.
- □ Accelerate the formation of habitat structures associated with large trees (e.g. supplementing natural tree hollows with artificial nest boxes). Salvaged tree hollows from trees that have been removed are preferred to constructed nest boxes. However, Lindenmayer *et al.* (2017) demonstrate that too great a reliance on artificial nest boxes may not advantage local populations of targeted hollow-dependent native species, and may even be detrimental to them.
- □ Proactively plan for future large trees by ensure that younger trees have sufficient "safe space" required to grow in size and using spatial zoning to minimise future risks.

b) Example 1: Riparian Corridors

Riparian corridors are among the most common urban habitat areas in need of restoration or construction. Urban drainage lines are essential for draining excess water from the surrounding landscape. Riparian areas associated with drainage lines not only provide critical habitat for biodiversity, but assist in maintain water quality by helping to filter pollutants such as nutrients and sediment, reducing bank erosion and maintaining stable drainage channel geomorphology. The vegetation also provides shade, which works to lower water temperatures. Lower water temperatures support higher dissolved oxygen levels which are important to maintain fisheries, and frog and aquatic invertebrate populations. Therefore, all these requirements need to be in balance when constructing or restoring riparian corridors. The following strategies are recommended:

- □ **Increase corridor width** to meet the biodiversity requirements described in Section 2.3.
- □ **Protect existing native vegetation and add additional native plants.** Locally-native plant species should be used to establish or enhance groundcover (herbs and grasses), understorey (shrubs) and overstorey layers, unless they were absent originally (e.g. a drainage line running through grassland). Spatially-uneven planting better simulates natural patchiness and provides areas of high- and low-density vegetation so that there is foraging, dispersal and breeding habitat for a broad range of species (Catterall *et al*. 2007). Native plants should flower, fruit and set seed in sufficient quantities and quality. If the corridor is designed to assist specific species (e.g. birds, bats or bandicoots), then their preferred food plant species should be used in habitat construction and restoration. Schematic cross-sections of riparian corridors designed to promote urban biodiversity are shown in Figures 3 and 4, and an actual constructed corridor is shown in Figure 5.
- □ **Lower the floodplain or raise the channel to promote hydrologic connectivity.** This will help replenish intermittent floodplain habitats (e.g. wetlands and ponds) that support aquatic and semi-aquatic fauna (e.g. frogs, turtles and invertebrates).
- □ **Create floodplain wetlands and topographical depressions.** Wetlands and depressions that vary in the amounts of time that they hold water helps to increase the diversity of habitat types for fauna (Tockner *et al*. 2000; Ward *et al.* 2002). They provide potential calling and breeding habitat for adult frogs, foraging habitat for tadpoles, breeding and foraging habitat for invertebrates, drinking habitat for vertebrates, and bathing habitat for birds.

Figure 3 **Typical cross-section of a living stream design promoted by the Western Australian Department of Water.**
Source: Stormwater Management Manual for Western Australia, 2004-07
(Chapter 9, Structural Controls). https://www.water.wa.gov.au/__data/assets/pdf_file/0019/1639/84981.pdf

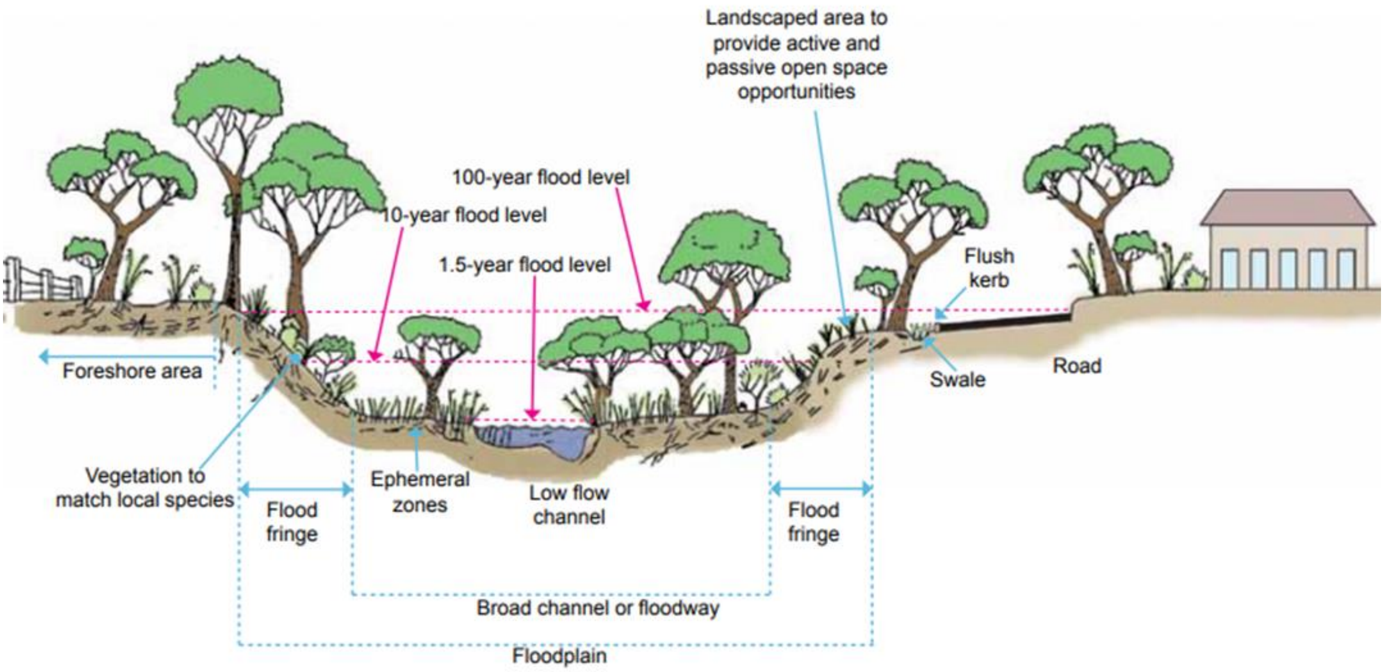


Figure 4 **Artist's impression of an urban drainage line for promoting biodiversity**
Source: Myers, Z. (2017). More Than Just Drains: Recreating Living Streams Through the Suburbs (The Conversation, 18 September 2017).
https://theconversation.com/more-than-just-drains-recreating-living-streams-through-the-suburbs-83345

Figure 5 **Landscaped urban Bannister Creek at Lynwood, Western Australia**
Source: South East Regional Centre for Urban Landcare.
https://www.sercul.org.au/our-projects/living-streams/

☐ **Retain dead trees and fallen timber.** Dead standing trees provide important roosting and nesting habitat for birds and mammals (Lynch & Catterall 2007). Fallen timber provides habitat for fungus (an important food source for some fauna species), invertebrates and ground-dwelling vertebrates. Decaying wood also returns organic matter to the soil.

☐ **Optional: fence off riparian zone.** This can help protect native fauna from introduced predators such as dog, foxes and cats (Lynch & Catterall 1999). However, it can also prevent dispersal of some fauna between wetlands and river systems (e.g. freshwater turtles). Sievert & Yorks (2015) provide a range of turtle tunnel and fence designs to aid the dispersal of turtles between freshwater habitats. Geller (2012) describes a simple electric fence design that protects turtle nests, but allows free-ranging turtles to disperse more widely.

☐ **Inoculate the soil.** Soil microbes and invertebrates may be absent from riparian areas that have been cleared extensively (e.g. greenfield sites and brownfield development), yet these organisms are essential for the breakdown of leaf litter and the release of nutrients into the soil. They can be reintroduced into the corridor by transporting leaf litter, dead wood and soil from intact riparian habitats.

☐ **Place street lights on the far side of adjoining roads.** Street lights can draw semi-aquatic insects away from the waterway and interfere with the foraging behaviour of other fauna (Scanlon & Petit 2009; Perkin *et al*. 2011; Senzaki *et al*. 2016). Artificial light spillage into riparian habitat areas can be reduced by locating street lights onto the far side of the road, angling them away from the riparian area, and planting dense vegetation along the outer edges of the corridor.

☐ **Protect from fire or burn appropriately.** Fires can destroy hollow-bearing trees and woody debris, and cause mortality or injury to fauna which can't escape the fires. Therefore, controlled burns should be avoided, or undertaken in such a way as to leave as little impact on flora and fauna and the quality of their habitats.

c) Example 2: Streetscape Plantings

Suburban street trees can provide habitat for some species of birds (Fernandez-Juricic 2000; Murgui 2007). However, Fernandez-Juricic & Telleria (2000) show that the complexity of vegetation cover plays a significant role, e.g. streets with canopy trees and no understorey or shrub layers, provide no habitat for species that forage close to the ground, and ground-foraging birds are more likely to be susceptible disturbances from pedestrian and vehicular traffic (the need for increased vigilance while foraging, and avoidance of traffic noise). Sorace (2002) also links increased predation risk to open treescapes as a deterrence to some birds, while Solonen *et al*. (1999) identifies the use of pesticides as a contributing factor. Therefore, a streetscape like the one shown in Figure 6 is likely to have lower bird species richness and diversity, than the streetscape depicted in Figure 7, which has a more diverse and complex vegetation structure that provides potential habitat for a broad range of bird species and their food items (invertebrates, seed, nectar and pollen).

Bird species richness and composition in urban streetscapes (White *et al.* 2005) and adjoining green spaces (Ikin *et al*. 2013b) are influenced by whether or not the street trees are native or exotic species. This is due in part to specific requirements of habitat specialists (e.g. suitable tree hollows, preferred food plants, and invertebrate prey occurring on particular plant species), the degree of shelter and potential nesting habitat that different tree species provide birds, and interactions between bird species that are attracted to exotic and nesting species.

Thinning of native woodland in urban areas of eastern and south-eastern Australia, either through the selective removal of large trees or through the removal of native understorey (e.g. tree saplings, woody shrubs) favours the colonisation and subsequent increases in abundance of Noisy Miners (*Manorina melanocphala)* in woodland (Clarke & Oldland 2007). Urban streets and parkland that are dominated by mature eucalypts without dense understorey and shrub layers also favours Noisy Miners. It is an aggressive species that chases conspecifics (Dow 1979) and other fauna species out of suitable woodland habitat (Grey *et al*. 1998; Debus 2008; Mac Nally *et al*. 2012). Ford (2010) concludes that the biggest challenges for reversing the loss of bird species richness and diversity in grassy woodlands are halting habitat loss and fragmentation, and providing suitable habitat that is not dominated by Noisy Miners. "Aggressive exclusion of birds from woodland and forest habitat by abundant Noisy Miners" is a listed Key Threatening Process under Schedule 4 of the NSW *Biodiversity Conservation Act, 2016* (BC Act).

High concentrations of Noisy Miners (Ford & Bell 1982; Howes & Maron 2007; Grey 2008) can lead to extensive woodland dieback, in which the canopies of eucalypt trees die back and in extreme cases can lead to tree death. For instance, extensive woodland dieback occurred between 2011 and 2013 in Cumberland Plain Woodland, a critically endangered ecological community occurring in urban areas of western Sydney, because clearing and thinning of woodland has progressively led to large numbers of Noisy Miners concentrating in areas of woodland that were retained. The dieback is usually the result of a psyllid outbreak in response to drought and reduced predatory pressure. Psyllids are small native cicada-like insects which live in colonies and produce a protective sticky lerp under which they live. Psyllid larvae suck the sap and plant juices out of the leaves of eucalypts and turning them yellow brown, eventually causing dieback and leaf drop. Miners do not feed on psyllids, but chase away small insectivorous birds that do feed on them, exacerbating the psyllid outbreaks and the extent of woodland dieback, which in turn further reduces fauna species and diversity in these habitats.

Figure 6 **A typical traditional Australian urban nature strip and neighbouring garden that have little native biodiversity value.**
Source: Sydney Morning Herald, 20 October 2019.
https://www.smh.com.au/lifestyle/health-and-wellness/we-re-a-city-of-forgotten-green-spaces-our-nature-strips-20191016-p531ai.html

Figure 7 **A Tokyo street nature strip with canopy trees and extensive shrub cover comprising a broad range of flowering plants**
Source: Myers, Z. (2017). Green for Well-being – Science Tells Us How to Design Urban Spaces that Heal Us (The Conversation, 28 August 2017).
https://theconversation.com/green-for-wellbeing-science-tells-us-how-to-design-urban-spaces-that-heal-us-82437

Examples of other urban-adapted species that competitively exclude smaller, more timid species from suitable urban habitat areas or from specific resources within the habitats in south-eastern Australia, include Bell Miners (*Manorina melanophrys*) (especially in riparian corridors with a very densely-vegetated understorey), Common Mynas (*Sturnus tristis*) (especially in private gardens and along roadside nature strips), Rainbow Lorikeets (*Trichoglossus moluccanus*) (known to oust other hollow-dependent species from tree hollows) and Red Wattlebirds (*Anthochaera carunculata*) (which chase other bird species away from nectar-rich plant sources). Overseas studies also show that bird species that are most successful in adapting to an urban environment are generally aggressive to other species, or comprise individuals that are more aggressive than their rural conspecifics (Foltz et al. 2015; Davies & Sewell 2016; Martin & Bonier 2018). Therefore, different urban vegetation and habitat structures are required for sustaining populations of a broad range of terrestrial bird species, including areas where more timid species can gain access to resources, as well as escape from aggressive birds that chase them. Tree-planting strategies developed by Ikin *et al.* (2013b) for sustaining bird groups of different conservation status' in urban areas are shown in Table 3. It takes into consideration the habitat requirements of urban birds, their susceptibility to disturbances, and their behavioural responses to other bird species.

Kennedy & Southwood (1984) found that more invertebrates were found on native than on exotic trees in urban environments of the United Kingdom, whereas Kendle & Rose (2000) suggest that may not always be the case.

2.5 Maintenance of Ecosystem Cycles

Ecosystem cycles (water and nutrient cycles) are altered significantly in urban environments. For instance, impervious surfaces such paved roads, concrete footpaths and rooftops produce large volumes of water after rainfall, which are ultimately transported to rivers, creeks and streams by stormwater drainage systems. This reduces the amount of water storage in soils and evapotranspiration back into the atmosphere (Walsh *et al.* 2012). Some world cities have reduced this problem by collecting the stormwater runoff and redirecting it to multiple locations where it can be used to irrigate parks, private gardens and other green spaces. This helps provide refugia for organisms that are vulnerable to drought or heat (Welbergen *et al.* 2008). A mosaic or irrigated and non -irrigated areas within a single park or over a broader area of a town and city helps provide a greater diversity and complexity of habitats, and thus increases the urban biodiversity (e.g. Newbound *et al*. 2010; Straka *et al*. 2016).

Selective clearing and thinning of native vegetation associated with urban development (including bushfire risk management measures) lowers the organic content of soils from falling leaves and wood decay. It also alters the water-holding capacity of the soils as a result of groundwater rising to the surface, leading to increased surface-water runoff. This depletes soil-borne microbial communities (bacteria) and other decomposer organisms (e.g. fungi and mites), which break down the organic matter and release nutrients into the soil. The reduction in organic matter and soil nutrients results in fewer nutrients being available for invertebrates (insects, terrestrial worms, snails etc.) that live on or close to the soil surface, and which are, in turn, food for insectivorous ground- and bark-foraging vertebrates (e.g. dasyurid marsupials, molossid bats and agamid lizards). The greatest decline in the distribution and abundance of woodland birds in southern Australia has occurred among insectivores that forage on the ground, on tree bark and in the air (bark and aerial insects develop from soil larvae). Watson (2011) believes that this is due to a significant reduction in soil invertebrates in response to the altered soil nutrient cycle, and suggests that this is the reason for similar declines in populations of other insectivorous vertebrates. Moreover, the increased runoff of surface water results in reduced tolerance of native vegetation to drought conditions, microbial communities to retreat deeper into the moister soil layers or entering quiescent stages, thus lowering the abundance of soil invertebrates, and the consequent compounding of drought stress experienced by insectivorous vertebrates. This demonstrates further the need for remnant habitat patches in urban areas to be retained as intact as possible, and for constructed corridors and urban parks to provide both diverse and complex habitats.

Table 3 Recommended tree planting strategies to attract birds into urban street landscapes and urban reserves (parkland, remnant vegetation patches, intact vegetated corridors) (from Ikin *et al*. 2013b)

Conservation Aim	Target Bird Group	Recommended Suburb Management Practices	Recommended Reserve Priorities
Birds present, no matter which or how many species.	"Any and All" Urban-adapted native and exotic species.	Native-provenance street trees.	Pockets of urban reserves to increase bird numbers in suburbs.
High numbers of native bird species, regardless of species diversity or formal conservation status.	"Native Favourites" Urban-adapted native species.	Native-provenance street trees. Low-traffic intensity boundaries between suburbs and reserves.	Pockets of urban reserves to increase bird numbers in suburbs.
High diversity of native birds, possibly but not necessarily including those with formal conservation status.	"Native Highlights" Urban-avoiding native species.	Greater focus on private gardens and habitat-enhanced open space (e.g. parks with a high habitat complexity). More research needed.	Combination of urban reserves to increase bird numbers in suburbs and areas of undisturbed reserves to increase bird numbers in reserves.
Increased numbers of birds with formal conservation status, e.g. threatened or migratory.	"Conservation Concern" Native "listed species".	Greater focus on private gardens and habitat-enhanced open space (e.g. parks with a high habitat complexity). More research needed.	Large, undisturbed areas away from the suburbs.

Table 4 Actions most appropriate for each strategy used to minimise urban impacts on biodiversity (from Parris *et al.* 2018).

Action	Protection	Connectivity	Construction	Cycles	Interactions	Benevolence	Novelty
Design to preserve features of high biodiversity.	X		X	X	X	X	
Preserve natural drainage lines (focus on the stream).	X	X	X	X	X	X	
Retain and use stormwater to enhance biodiversity.	X			X		X	
Take advantage of urban turnover.	X		X			X	X
Use temporary or neglected spaces				X	X		X
Engage the general community.	X		X	X	X	X	X
Co-ordinate public and private actions.	X	X	X	X	X	X	X
Use the "carrots and sticks" (community rewards) approaches to protecting the natural environment.	X	X	X	X		X	
Incorporate biodiversity-sensitive practices into existing urban management.				X	X		
Councils and the broader community to actively promote a "green and biodiverse city" through planning regulations.	X	X	X			X	X

2.6 Interactions Between Ecosystem Components

Urbanisation can alter interactions between organisms, such as competition for resources, pollination and parasitism, which can have flow-on effects throughout the urban ecosystem. For instance, pollination of flowering plants is crucial for the maintenance of urban native plant diversity and urban farming (Normandin *et al.* 2017; Threlfall *et al.* 2015). A decline in the diversity and abundance of pollinators (e.g. native bees, butterflies, wasps and nectar-feeding birds) across an urban landscape can result in the local extinction of plant species dependent on these specialist pollinators. Some of these impacts can be avoided or minimised by protecting important habitat and ecological assets, maintaining, creating and enhancing connectivity between important habitat areas, and constructing diverse and complex habitats.

2.7 Benevolence of Urban Forms

Urban structures and anthropogenic activities can significantly increase the risk mortality to wildlife species (e.g. bird-window collisions and wildlife-vehicle collisions). But disturbances such as artificial night light (Ambrose 2020a,b) and anthropogenic noise (Ambrose 2020c) can significantly alter an animal's behaviour, cause cellular, tissue and organ damage, elevate physiological stress, and impact on an animal's reproductive success and longevity. These disturbances can compound the impacts of habitat removal and degradation and, in a worse case situation, contribute to the extinction of local populations.

Australia's draft National Light Pollution Guidelines for Wildlife (DEE 2019) prescribes the following management principles to reduce light pollution:

- start with natural darkness and only add light for specific purposes;
- use adaptive light controls to manage light timing, intensity and colour;
- light only the intended object or area – keep lights close to the ground, directed and shielded;
- use appropriate lighting;
- use non-reflective, dark-coloured surfaces; and
- use lights with reduced or filtered-out blue, violet and ultraviolet wavelengths.

The most common approach to minimise noise impacts associated with transportation, industrial activity and general urban environmental noise is to erect physical barriers (Shannon *et al*. 2015). Simple modifications to windows can reduce bird strikes (Ogden 2014), and wildlife mortality can be reduced by imposing lower vehicle speed limits and creating vehicle-free city roads (Cittaslow 2016; Gehl 2010), and the use of wildlife crossings and underpasses (e.g. Mimet *et al.* 2016; Clevenger *et al*. 2001).

2.8 Novel Ecological Communities and Ecosystems

The importance of new urban ecological communities (e.g. private gardens, constructed wetlands, public parks, rehabilitated industrial sites) in supporting biodiversity, and which have novel habitat structures and species associations, needs to be recognised and embraced (Chester & Robson 2013; Serret *el al*. 2014; Threlfall *et al*. 2016).

2.9 Predation

Protection, restoration and creation of habitat for native biodiversity in urban areas, also increases the risk of predation of wildlife by domestic cats, urban foxes, and predation and disturbances from pet dogs. This can occur through the use of introduced predators dispersing along habitat corridors to important habitat areas (pet cats and urban foxes) or occurring in increased densities (e.g. pet dogs in parks). Well-structured habitats also offer added concealment to predators that are hunting. Attracting wildlife to urban habitats could also potentially result in ecological trapping, i.e. potential prey species coming into greater contact with introduced predators.

Introduced cats (*Catus felis*) have had profound impacts on native faunas in many places, contributing to 26% of the total extinctions of mammals, birds and reptiles globally since 1600 (Doherty *et al.* 2016). In Australia, pet cats outnumber feral cats, at least in most years (3.77 million pet cats versus 2.8 million feral cats, Legge *et al.* 2017; AMA 2019). Urban areas contain both feral and pet cats. Cats mostly hunt species according to their relative abundance in an area (Doherty *et al.* 2015), but individual cats often specialise on particular species or species groups (Dickman & Newsome 2015; Moseby *et al.* 2015). Pet cats live at much higher densities, so the predation rate of pets per square kilometre in residential areas is 28–52 times larger than predation rates by feral cats in natural environments, and 1.3–2.3 times greater than predation rates per square kilometre by feral cats living in urban areas (Legge *et al.* 2020). This predation pressure has the potential to place some fauna populations at risk of local extinction. Ecological consultants help reduce this predation pressure by educating people about the risks that cats pose on native wildlife, and advising cat owners to confine their pet cat to inside their home or to enclosed outside cat runs.

Although well-adapted globally to living in urban environments, European Fox (*Vulpes vulpes*) numbers and distribution are likely to have changed since the 1990s, including: localised increases in density in response to anthropogenic feeding (Baker *et al*. 2000; Soulsbury *et al*. 2007); outbreaks of mange (Soulsbury *et al*. 2007); the colonisation of additional cities and towns, including some previously considered unsuitable for foxes (Wilkinson *et al*. 2001); periodic population explosions in urban rodents (SMH 2019); widespread fox-baiting programs (OEH 2010); and the general expansion and changing structure of urban areas in response to a growing human population (Pauleit *et al*. 2005; Baker & Harris 2007). Threatened species that are known to be prey items of foxes in the Sydney Basin Bioregion include: Pied Oystercatcher (*Haematopus longirostris*), Little Tern (*Sternula albifrons*), Green and Golden Bell Frog (*Litoria aurea*), New Holland Mouse (*Pseudomys novaehollandiae*), Bush Stone-curlew (*Burhinus grallarius*), Powerful Owl (*Ninox strenua*), Long-nosed Bandicoot (*Perameles nasuta*), Eastern Pygmy-possum (*Cercartetus nanus*) and Rosenberg's Goanna (*Varanus rosenbergi*) SCC Group 2017). Specialist ecological consultants play an important role in controlling urban foxes by developing and implementing threat abatement plans and monitoring their effectiveness.

Dog walking in woodland leads to a 35% reduction in bird diversity and 41% reduction in abundance, both in areas where dog walking is common and where dogs are prohibited (Banks & Bryant 2007). However, Weston *et al*. (2014) say that the disturbance impacts of pet dogs in urban parks and public spaces is poorly understood. Impacts on wildlife can be minimised by owners keeping their dogs on a leash in public areas, and avoiding the walking of their dogs in medium- to high-conservation value habitat areas.

CONCLUSION

A summary of the actions that are most appropriate for each of the biodiversity strategies discussed in Sections 2.2 to 2.8 are shown in Table 4. A key component of maintaining and enhancing urban biodiversity is engaging the general community in the development of biodiversity policies and regulations, implementation of conservation actions, and to develop a sense of public ownership of conservation ideas and outcomes. As ecological consultants, we are in a unique position to drive that community involvement through encouraging our clients to accept actions that will improve biodiversity outcomes from their proposed developments, advising governments at all levels about appropriate biodiversity policy and regulation, educating the community about important biodiversity issues, helping to co-ordinate community involvement in implementing conservation actions, monitoring more widely and intensively the effectiveness of these actions, and having a more wholistic approach to our work, rather than dealing with ecological issues on a site-by-site basis. I can just hear all of you saying now that we do this already. My reply is, do we really?

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THREATENED PLANT TRANSLOCATION AS A DEVELOPMENT MITIGATION

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Ecological Consultants require a diverse skill set to navigate the requirements of legislation, developments and biodiversity protection. Increasingly, we are called on to provide advice about threatened species management beyond *in-situ* avoidance and mitigation of impacts. In this context, consultants need to balance aspiration, realism, costs and client satisfaction with limited scientific evidence, while also meeting their ethical obligations. Removal of threatened species from a development footprint to an alternative location is now regularly recommended in impact assessments and required as a condition of development consent to offset impacts. However, legislation and policy at Commonwealth and State level discourage the use of translocation as tool for mitigation.

Policy under the EPBC Act states that - "*a translocation associated with an action will be unlikely to be approved. For actions referred under the EPBC Act, the low success of translocation proposals mean that unless it can be shown that there is a high degree of certainty that a translocation will be successful in contributing to the long term conservation of the species or community, a proposal will be unlikely to be approved*" (Policy Statement - Translocation of Listed Threatened Species, Assessment under Chapter 4 of the EPBC Act).

Recently released NSW General Principles of Translocation (Translocation operational policy DPIE 2019) state that – "*Translocation is not generally an appropriate measure to mitigate the impacts of development and may do more harm than good where impacts to recipient site(s)/ecosystem(s) are not appropriately assessed and addressed.*"

While the NSW policy details various aspects and requirements for translocation under a license, translocation as part of a development proposal does not require the preparation and submission of a translocation proposal or the issuing of a license. Translocation under these circumstances is governed by the project consent/approval conditions. Approval is covered by the EP&A Act with the following note: "*However, a BC license may be required if the release site is not covered by the development consent, approval or authority.*"

The NSW policy also states that "*All translocation initiatives should actively contribute to learning and knowledge generation through transparency and public dissemination of results*". However, there is no mechanism to ensure that this happens. Although the species that will be translocated are recorded in project approval documentation, it is not possible (in a time-efficient way) to locate and extract the details of which species is being translocated and how that is to occur. Nor is it possible to access information on the methods, longevity of monitoring, short term success/failure or long-term creation of new "self-sustaining" populations, the theoretical goal of a translocation (Commander 2018). This valuable information that would inform and improve outcomes of future translocations is buried in project approvals and reporting. There is no mandatory requirement for species translocation to be reported. There is no central, easily accessible register of species translocation in NSW or for Australia as a whole.

A well-developed root system of *Hibbertia spanantha* Toelken & A.F.Rob propagated from cuttings in an glasshouse, being transplanted into habitat similar to that of the donor population as part of the consent conditions of a development project. Monitoring of the species after planting found that all plants had died after 2 years. Cuttings of *Epacris purpurascens* planted at the same time in the same location were still alive after 2 years. This work will contribute to a publication (Doyle *et al.* in prep.) and ongoing research into translocation of the *Hibbertia*. Thanks to the initiatives of the consultant, the causes of the successes and failures from the initial translocation (which could contribute to the next attempt at translocation of these species by others) would typically have been buried in project paperwork and reporting and functionally unavailable to others. (Image courtesy of Chantelle Doyle)

In 2019, Silcock *et al*. published a paper on plant translocation in Australia. This publication was based on data contributed on a voluntary basis to the Australian Plant Translocation Database supported by the Threatened Species Conservation Hub. Using data from the database a list of plant translocations that were part of development mitigation was compiled. Silcock *et al.* (2019) found that over 85% of translocations in Australia have occurred since 2000 and half since 2010, with an especially rapid increase in development mitigation translocations, which account for 30% of all translocations documented (Figure 1). It is important to remember that this is a voluntary database and by no means a comprehensive record of all plant translocations in Australia. Examination of the data for development mitigation translocation shows that 227 records of mitigation translocation (between 1980 and 2017) out of a total for Australia of 388 occurred in NSW. These 227 records were contributed by 14 consultants only, and the majority of the translocations occurred since 2006 (Table 1). In contrast, the official licencing system for the State and the Commonwealth have the following records of licences issued for plant translocation.

- NSW Section 91 licence: 15 (2006 – 2017)
- Commonwealth EPBC Act permit: 1 in 2013; 1 in 2018.

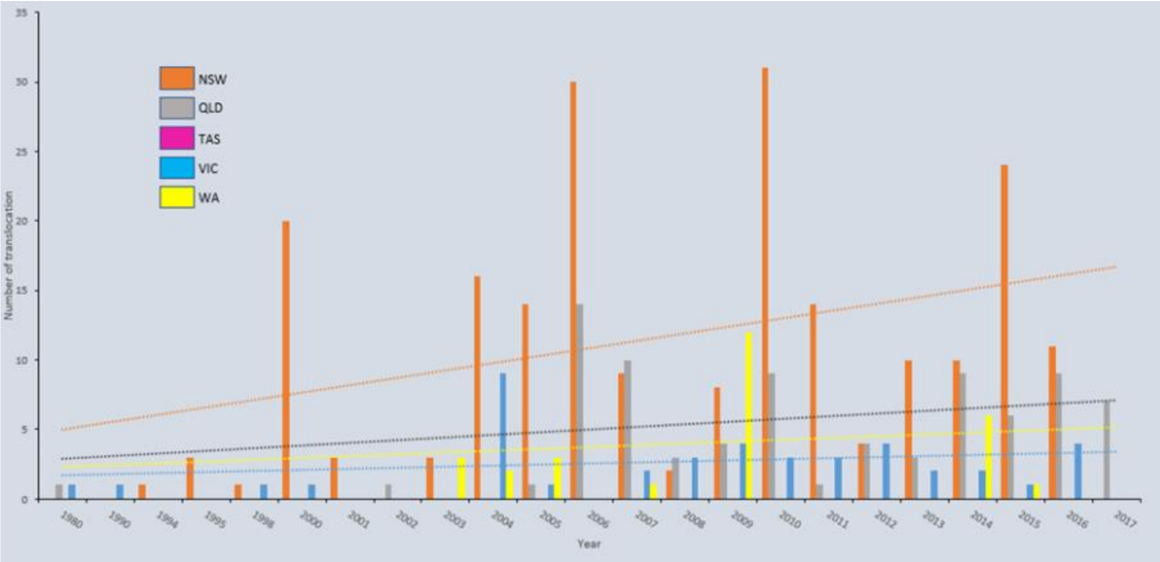


Figure 1: Distribution of translocations attributed to development mitigation between states and by year (from Silcock *et al.* 2019)

State	Total Records (Development Mitigation) 1980-2017	Number of Consultants	Records attributed to one consultant	Number of species
NSW	227	14	179	67
QLD	90	28	19	55
TAS	1	1		1
VIC	42	12		11
WA	28	8		12
TOTAL	388			

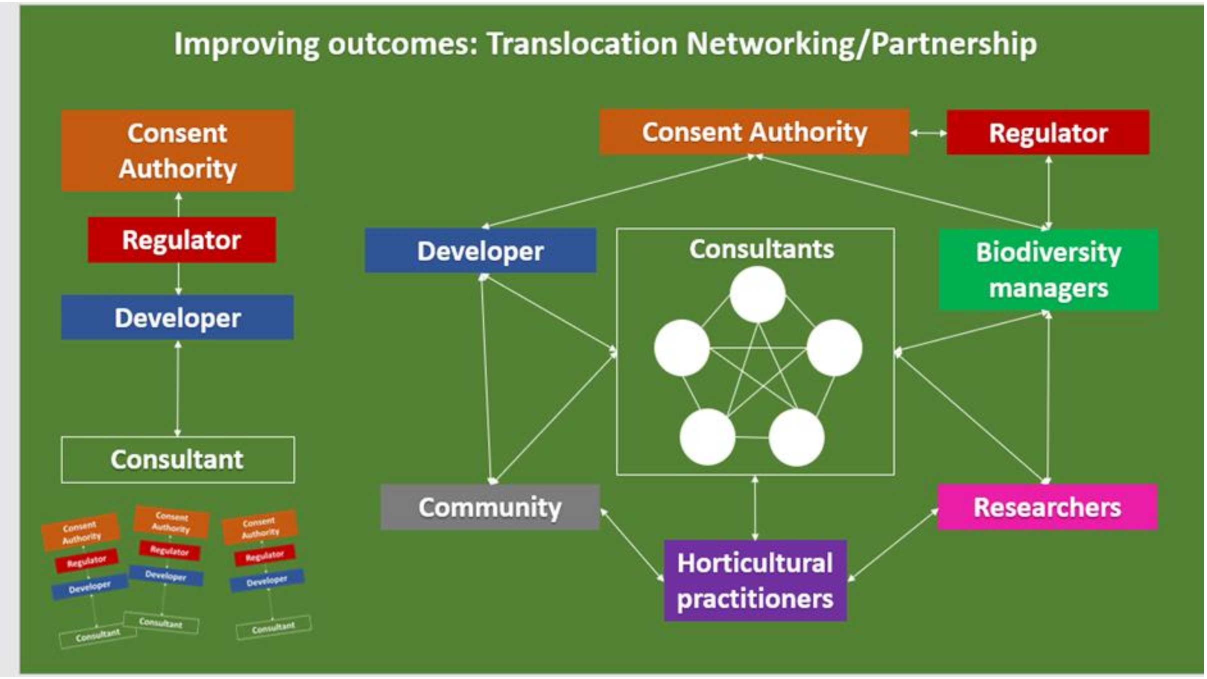
Table 1: Distribution of plant translocation records and sources by state (from Silcock *et al.* 2019)

Well-designed monitoring is needed to improve understanding of the translocation process and build knowledge on species-specific requirements. Sharing this information, however, can sometimes be challenging depending on the willingness of clients who own the data. There are also few mechanisms or economic incentives that exist to make translocation data from development projects available. Other historical impediments include the lack of a central repository for translocation data and the absence of statutory responsibilities to maintain data on this important aspect of plant conservation.

Development of a systematic, publicly-available information base of when, where and how plant translocations have succeeded or failed, and promoting the transfer of this knowledge should become important priorities for biodiversity conservation, particularly as translocations are increasingly relied upon to offset development impacts.

Outcomes for plant translocation would be improved significantly if a different approach to translocation was adopted by state and commonwealth governments. The current minimalist approach works in a restrictive, linear fashion, and these projects are typically about the developer satisfying the consent authority and minimising regulatory interaction (Figure 2 left). In the current linear format, there is no opportunity to exchange accumulated knowledge nor compare processes and outcomes between translocation projects. A better system would facilitate exchange of knowledge, and projects with more stakeholder contribution which are likely to achieve better outcomes (Figure 2 right). Here, there is an exchange of information between stakeholders and consultants facilitated by a central system dedicated to recording all translocation and their outcomes. Under this scenario, consultants can become a valuable repository of knowledge accumulation and sharing.

Figure 2. Improving the outcome of translocations



Why do plant translocations fail?

- Most translocation undertaken by consultants is not publicly documented.
- Mismatch between documented translocation and actual works being undertaken.
- No central record of impact mitigation translocations and outcomes.
- Knowledge transfer and communication is important to translocation success. Development approvals and consent conditions need to acknowledge the high risks of translocation failure under current limitations to knowledge (species specific) and technology.

How can plant translocation outcomes be improved?

- Through networking and partnerships.
- By establishing a central register and mandatory reporting for all translocations.
- From more engagement of research:
  - by increasing the level of networking between stakeholders; and
  - by increasing contact between developers, consultants and researchers in reciprocal partnerships.
- By engaging the community in ongoing monitoring and *in situ* care.
- By building knowledge base in consent authorities.
- By openly communicating reasons for failures, without fear of revoking of consent.

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ECA Photo Gallery

LEFT: Varied Sittella. RIGHT: Eastern Yellow Robin. *Photo courtesy of Phil Cameron.*

LEFT: *Photo courtesy of Geraldene Dalby-Ball.*

ABOVE: Coastal Wetland. BELOW: Coastal Vegetation Management, Avalon. BELOW LEFT: Natural remnants in Rouse Hill. *Photos courtesy of Geraldene Dalby-Ball.*

ECA Photo Gallery

RIGHT: 2020 New Growth. *Photo courtesy of Tim Johnson.*

RIGHT: *Photo courtesy of Ryan Herbert.*

ABOVE: Eastern Grass Owl. *Photo courtesy of Steve Sass.*

BELOW: Saltmarsh in Wentworth point Sydney Olympic Park. *Photo courtesy of Geraldene Dalby-Ball.*

Right: Caladenia gracilis at Cullen Bullen, Oct 2018 . (ID not confirmed) *Photo courtesy of Stephanie Clark.*