



# Novel resources: opportunities for and risks to species conservation

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During the Anthropocene, ongoing rapid environmental changes are exposing many species to novel resources. However, scientists' understanding of what novel resources are and how they impact species is still rudimentary. Here, we used a resource-based approach to explore novel resources. First, we conceptualized novel resource use by species along two dimensions of novelty: namely, ecosystem novelty and resource novelty. We then examined characteristics that influence a species' response to a novel resource and how novel resources can affect individuals, populations, species, and communities. In addition, we discuss potential management complications associated with novel resource use by threatened species. As conservation and management embrace global environmental change, it is critical that ecologists improve the current understanding of the opportunities and risks that novel resources present to species conservation.

*Front Ecol Environ* 2020; doi:10.1002/fee.2255

As the direct and indirect impacts of human activities, including land transformation, climate change, and species turnover, continue to alter natural processes and ecosystems (Vitousek *et al.* 1997), evidence is emerging that many species are using new resources (eg food, structures) within their altered environments. For some taxa, these novel resources – previously absent or unavailable resources that are affiliated with human activity and are now used by many species; see full definition below – have become so important that their use has changed foraging behavior, breeding activity, and

predator–prey dynamics (Ortega *et al.* 2014; Lewis *et al.* 2015; Fleming and Bateman 2018). In addition, with respect to imperiled taxa, some have adapted to anthropogenic environments and novel resources (Price *et al.* 2011; Becker and Buchholz 2016), while others seemingly display a preference for habitats dominated by novel elements over their native environments (MacClagan *et al.* 2018; Wolf *et al.* 2018). Urban areas in particular offer a range of novel resources, and are also characterized by greater rates of phenotypic change in animals and plants (leading to contemporary evolution) than non-urban anthropogenic and natural systems (Johnson and Munshi-South 2017; Thompson *et al.* 2018). There is a need to better understand how species exploit and are influenced by novel resources, especially where conflicting management objectives may arise. For example, a subset of threatened species have become reliant on non-native and even invasive species that now provide essential habitat resources (Bean and Dudley 2018), which creates major challenges to conservation. Here, we explore the concept of novel resources, how species use and respond to these resources, and their implications for the management of threatened species.

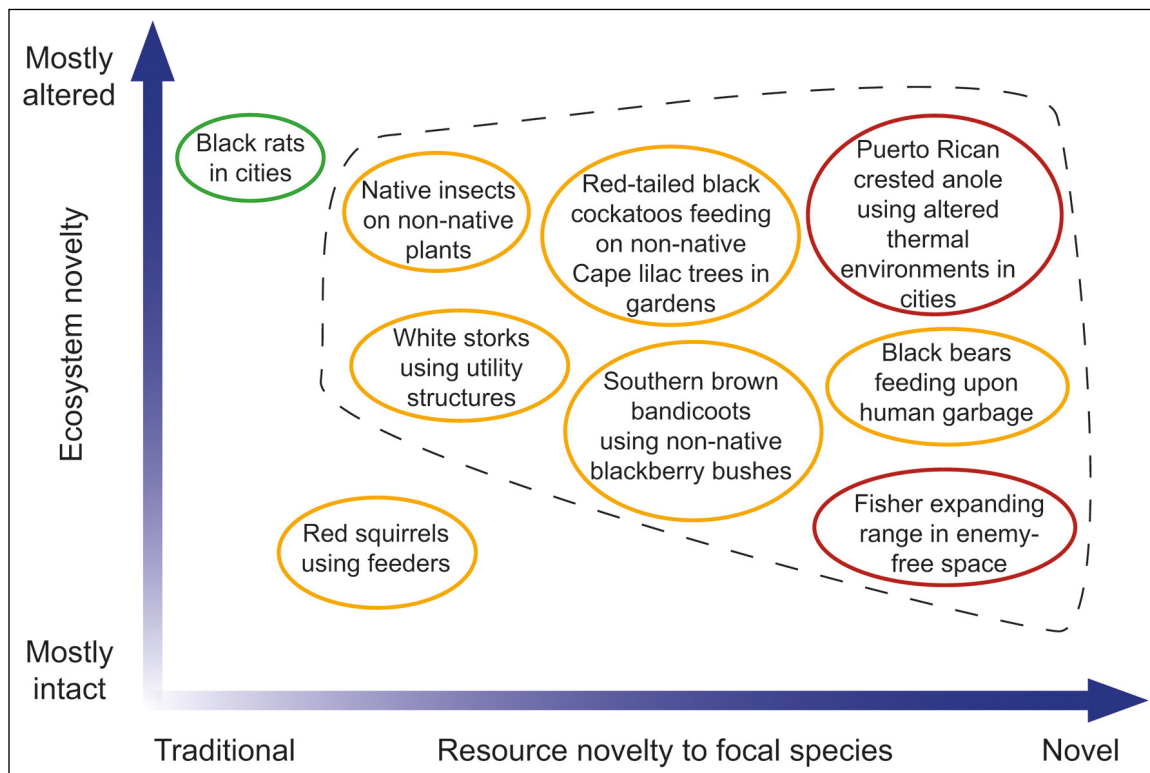
## In a nutshell:

- A consequence of human-mediated environmental change is that species are increasingly exposed to novel resources, which we define from a conservation and management perspective
- Novel resources can affect species on many levels, including individual attributes such as behavior and health to population dynamics, species distributions, and community interactions
- Conservation practitioners must have an improved understanding of the opportunities and risks provided by novel resources, which are used by many species, including threatened taxa, and which present challenges to management efforts

## ■ What are novel resources?

Despite the prevalence of the term “novel resource” in the ecological literature – from understanding invasive species traits (Sol *et al.* 2011), to behavioral shifts of species adapting to novel anthropogenic resources (Lewis *et al.* 2015), to evolutionary traps (discussed below; Robertson *et al.* 2013) – it has not been properly defined, nor its breadth conceptualized, especially in relation to its relevance for wildlife conservation and management. We believe that describing novel resources is nuanced because, while “novel” indicates a departure from a traditional resource (here considered to be a resource that

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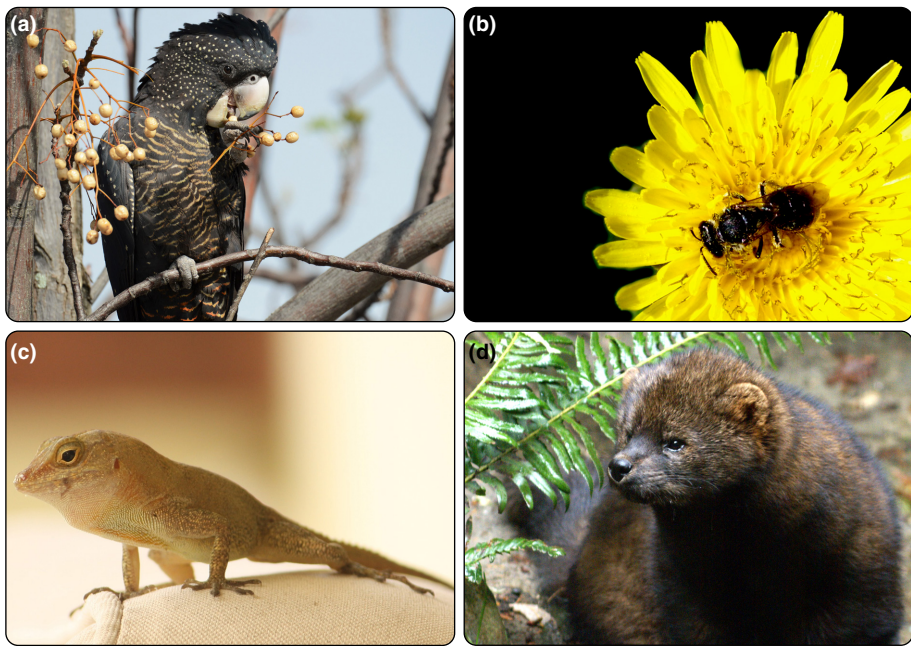
**Figure 1.** Conceptual representation of novel resource use by species along two gradients: the resource novelty to the focal species and the ecosystem novelty in which the resource is being used. Circled examples are discussed in the text and color indicates the resource type (green = not a novel resource; orange = consumable novel resource; red = utility novel resource). Most use of novel resources by species will occur within the area encompassed by the dashed line, although species can use novel resources outside this boundary.

a species has co-evolved with), the extent of this departure or novelty is temporally and spatially framed from the context-specific perspective of the focal species, and is influenced by the scale of change in the broader environment. Therefore, we propose novel resources be defined as the recent use of resources by a focal species, where (1) those resources are known not to be part of that species' traditional, native "portfolio" of resources used in a particular region; and (2) the emergence and availability of those resources are likely to be the result of direct or indirect human influence on the environment. Given the species-specific context of novel resources, the term "recent" in our definition is necessarily arbitrary, and will vary depending on what is relevant from a co-evolutionary perspective of the focal species and the resource in question (see below). However, a logical approach is to loosely adopt a potential start date of the Anthropocene (~1950, the time of initial evidence of major human-driven socioeconomic and biophysical Earth-system changes known as the Great Acceleration; Steffen *et al.* 2015) as a reference timeframe. Although a few species may have used novel resources prior to 1950 (eg long-lived species), many others may now be beginning to use novel resources, while others will do so only in the future.

We propose that examples of novel resources can be arranged along two dimensions of novelty: ecosystem novelty and resource novelty (Figure 1). The recent descriptions of

ecological novelty by Heger *et al.* (2019), which encompass the consequences of global change (a site-specific perspective) and incorporate aspects of the focal species' evolutionary past (an organism-specific perspective), provide a useful framework for our examination of novel resources along these two dimensions of novelty. Our concept of novel resources complements the broad framework provided by Heger *et al.* (2019) by examining in detail a specific element: the use of a novel resource by a focal species, further understanding of which may contribute toward improved management decisions for both the species and the resource. The ecosystem novelty dimension and species-specific approach of our framework align well with Heger *et al.*'s (2019) site-specific and organism-specific perspectives, respectively, of ecological novelty.

In our framework, ecosystem novelty reflects the range of environmental conditions (from mostly intact to markedly altered ecosystems; Figure 1) that species are exposed to when they use novel resources. Increasing awareness of our changing world and the development of concepts such as novel ecosystems (Hobbs *et al.* 2009, 2013; Morse *et al.* 2014) and ecological novelty (Radeloff *et al.* 2015; Heger *et al.* 2019) has generated discussion on the value of such modified environments. Ecosystem novelty may influence habitat attributes (eg resource availability) that may determine whether (and how) a species uses a novel resource. The suite of characteristics (eg structures, species, processes) associated with an ecosystem



**Figure 2.** Images of species that use novel resources (from Figure 1), including (a) forest red-tailed black cockatoos (*Calyptorhynchus banksii naso*) feeding on non-native cape lilac trees (*Melia azedarach*) in gardens; (b) native insect on a non-native garden plant; (c) Puerto Rican crested anole (*Anolis cristatellus*) using altered thermal environments in the built environment; and (d) fisher (*Pekania pennanti*) expanding its range in enemy-free space.

modified by habitat conversion likely differs from the characteristics of that same ecosystem's historical unmodified state (Heger *et al.* 2019), to which its originally affiliated species have co-evolved. Therefore, we suggest that as ecosystem novelty increases, so too does the potential for the presence of novel resources, and that the use of novel resources by species is more likely to occur in highly modified or novel ecosystems (Figure 1). Many of the examples that we selected to explore the concept of novel resources, which are presented below (see also WebTable 1), are set in highly modified ecosystems, such as cities. However, species may also use novel resources in less modified or relatively intact ecosystems, such as red squirrels (*Sciurus vulgaris*) exploiting supplementary feeders in mostly intact habitat (Starkey and delBarco-Trillo 2019).

By way of comparison, resource novelty occurs along a traditional–novel gradient, which reflects the exposure of a focal species to a resource over relevant generational time frames. For instance, within recent decades threatened forest red-tailed black cockatoos (*Calyptorhynchus banksii naso*) have begun foraging on the non-native cape lilac trees (*Melia azedarach*) that are frequently planted along residential streets and in gardens in Perth, Australia (Figure 2a; Johnstone *et al.* 2017). Traditional (or historical) resources include those native and anthropogenic resources with which a species has shared a long co-evolutionary history. “Anthropogenic resources” is a term that is on occasion used synonymously with novel resources, with much of the anthropogenic resource literature focusing on human provisioning of resources for wildlife (eg

human garbage, bird feeders; Newsome *et al.* 2015; Cox and Gaston 2018). However, by drawing on recent definitions of novelty that incorporate a species' eco-evolutionary history (Heger *et al.* 2019), anthropogenic resources may or may not be novel, depending on the specific species using the resource and their co-evolutionary history with the resource. For example, black rats (*Rattus rattus*) have used anthropogenic structures in cities for centuries (Aplin *et al.* 2011); although these resources would at one time have been novel to black rats, they are unlikely to contain much novelty to the species now, after hundreds of generations. In contrast, increasing use of electricity pylons as novel nesting sites by white storks (*Ciconia ciconia*) in Portugal (Moreira *et al.* 2018) is a more recent co-evolutionary phenomenon and linked to the Anthropocene.

## ■ How do species use novel resources?

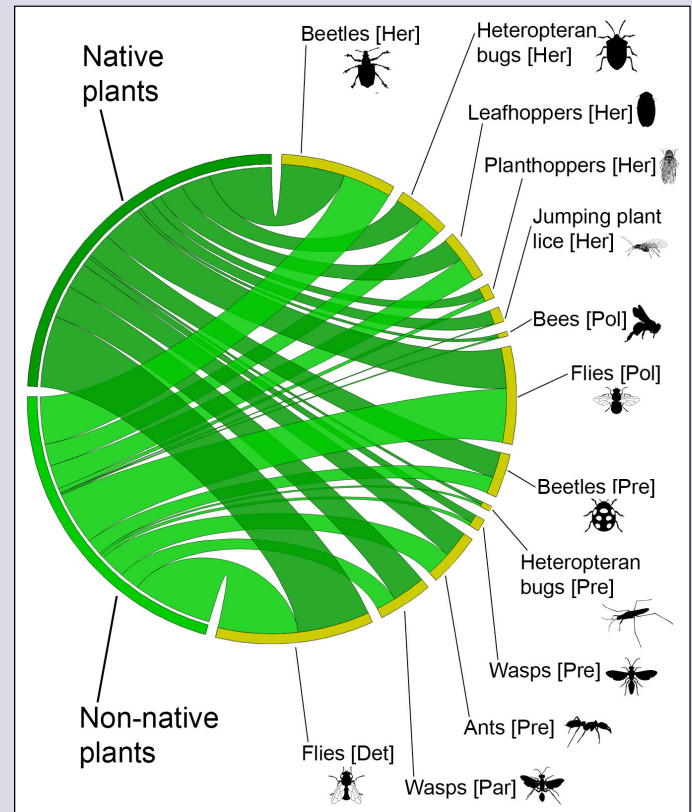
We applied a resource-based approach – one that is intrinsically organism-focused and considers the requirements of species in terms of “consumables” and “utilities” (Dennis *et al.* 2003) – to explore examples of novel resource use by species. Consumable resources are those that satisfy a function or facilitate a behavior (eg breeding, feeding, thermoregulation, shelter, dispersal), whereas utility resources include the environmental conditions required for development, persistence, and survival (eg microclimate and enemy-free space; Dennis *et al.* 2003). By enemy-free space we mean conditions that reduce or eliminate a species' vulnerability to a natural predator, parasitoid, or parasitic enemy (Jeffries and Lawton 1984). Although in this paper we focus on how species use novel resources, we recognize that not all species will use a novel resource. Species-specific traits, including behavioral plasticity and adaptive capacity (Ortega *et al.* 2014; Kennedy *et al.* 2018), will influence whether and how a species uses novel resources.

A vast array of organisms use consumable novel resources (eg anthropogenic structures, human food and waste, non-native species) to meet a range of needs (WebTable 1; WebFigure 1). Many native insects forage on or shelter in a variety of plant species, commonly relying on both native and non-native plants to fulfill their resource requirements through a mix of traditional and novel resources (Figure 3; Panel 1; Mata *et al.* 2016). Conversely, many native plants in altered landscapes have become dependent on non-native honeybees and bumblebees as their sole or complementary pollinators



### Panel 1. Non-native plants as novel resources for city-dwelling native insects

The blend of planting practices in city greenspaces translates into a wide array of traditional and novel resources being available to insect species. The relationships that insects establish with these plants vary tremendously. Herbivorous taxa among beetles (eg weevils) and hemipteran bugs (eg leafhoppers) exploit plant food resources (eg leaf tissues) antagonistically, whereas pollinators such as bees (eg blue-banded bees, *Amegilla* spp) and flies (eg hoverflies) gain access to flower resources (eg nectar, pollen) for mutual benefit. Taxa in other functional groups, including predatory beetles (eg ladybugs) and ants (eg bull ants), parasitoid chalcidoid wasps, and detritivores (such as most house, blow, fruit, and signal fly species), do not directly utilize plants as food but benefit from the habitat resources provided by living and non-living plant structures. To explore how insects in cities interact with novel food and habitat resources, we analyzed the “little things that run the city” meta-network, a dataset that embodies research into plant–insect interactions in urban areas (Mata *et al.* 2016). The meta-network describes the interactions between 107 plant species (50 native, 57 non-native) and 558 insect species (539 native, 19 non-native) within 15 greenspaces in Melbourne, Australia. We categorized the native insect species into 13 groups based on their evolutionary lineage and functional role, and summarized the frequency by which these groups interacted with native and non-native plants (Figure 3). Insect species within all groups interacted frequently with novel plant resources (light green ribbons in Figure 3). This highlights how insect communities are adapting, and potentially co-evolving, to use the spectrum of novel resources provided by non-native plant species in urban environments.



**Figure 3.** Meta-network of ecological interactions between native (dark green) and non-native (light green) plants and 13 insect groups (black) across 15 greenspaces in Melbourne, Australia. Her: herbivores; Pol: pollinators; Pre: predators; Par: parasitoids; Det: detritivores. Data from Mata *et al.* (2016).

(MacIvor *et al.* 2017). Several wildlife species use human-built structures, often analogous to traditional resources, as novel breeding and roosting sites (Caballero *et al.* 2016; Moreira *et al.* 2018) or for substrate-adherence opportunities (Guerra-Garcia *et al.* 2004). The increasingly common occurrence of animals, such as American black bears (*Ursus americanus*), foraging on human garbage and waste products (Lewis *et al.* 2015; Newsome *et al.* 2015) is a good example of novel resource use where the new resource is very different from traditional resources. Novel resources can also satisfy essential habitat requirements for threatened species (WebTable 1), with examples including non-native plant species providing novel shelter, food (Packer *et al.* 2016; MacClagan *et al.* 2018), and nesting opportunities (Price *et al.* 2011).

Altered environmental conditions, such as increased temperatures in cities due to the combination of climate change and urban heat island effects, may provide novel utility resources. For example, Puerto Rican crested anoles (*Anolis cristatellus*) are increasingly utilizing warmer thermal environments in urban habitats (Figure 2c; Winchell *et al.* 2016), and higher temperatures, coupled with reductions in frost events, are

contributing factors to the establishment of permanent camps (outside their historical range) of threatened gray-headed flying foxes (*Pteropus poliocephalus*) in Melbourne, Australia (Parris and Hazell 2005). Novel utility resources could also include the human-mediated removal of top-order predators that results in mesopredator release, whereby a focal species utilizes the novel enemy-free space (WebTable 1; LaPoint *et al.* 2015).

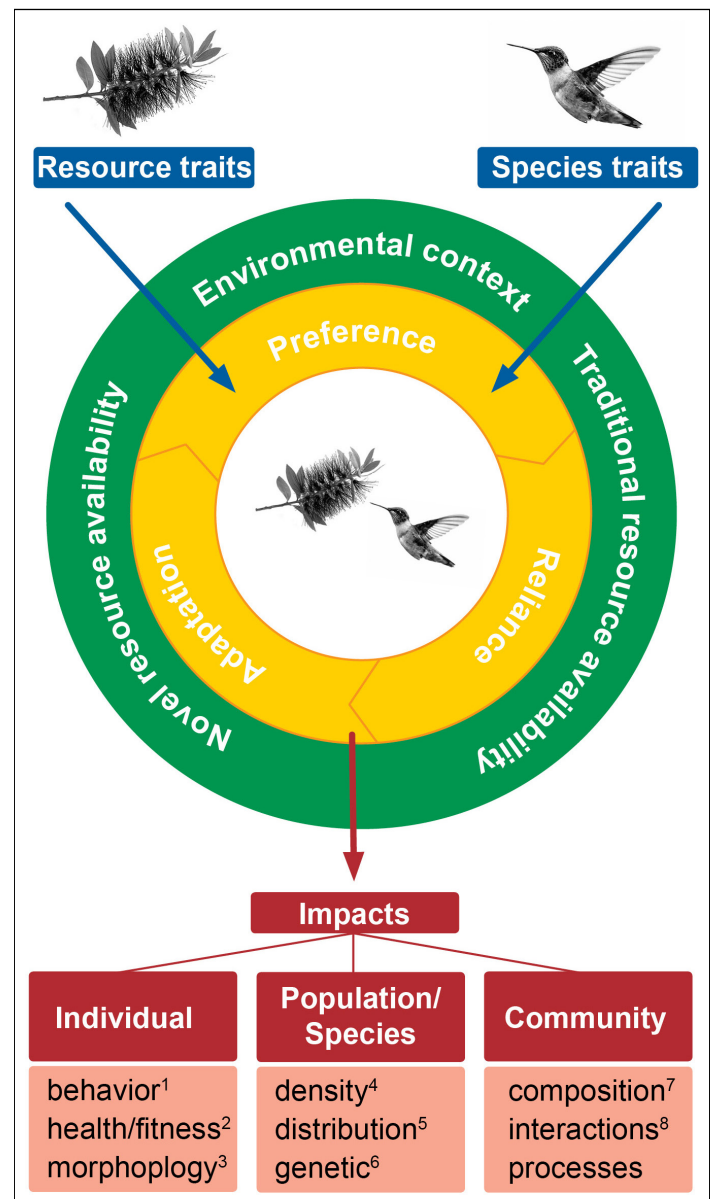
### ■ How do novel resources influence species?

The traits of a particular species and of a particular resource may influence how the resource is used by, and how it affects, the species (Figure 4). For example, novel resources that are similar (ie analogous) to traditional resources do not necessarily require new skills or behavioral learning and may be less novel to a species than a resource for which use requires some behavioral flexibility (Kennedy *et al.* 2013). The effects of novel resources will therefore depend on many interacting factors, including (1) the species' reliance on, preference for, and adaptation to the novel resource; (2) the availability of the novel resource, as well as the

availability of alternative resources (traditional or novel); and (3) the environmental context under which the resource is being used (Figure 4). Environmental context in this sense encapsulates the ecosystem novelty component and the diverse array of potential external pressures (eg predation, habitat loss) influencing the use of novel resources by a species. Novel resources and their use can influence organisms on multiple levels (Figure 4; WebTable 1), including effects on individual traits (eg health; Murray *et al.* 2015), population dynamics (eg density; Claassens and Hodgson 2018), species distributions (Hobbs *et al.* 2018), and community-level species interactions (Buettner *et al.* 2013). Furthermore, by altering species interactions, there is the potential for novel resource use by species to have indirect effects that result in changes to ecosystem processes.

Understanding how reliant a species is on the resource (eg as a food item, is it a tasty “treat” or is it essential to survival?) will be important for the conservation and management of threatened species, especially if traditional resources are scarce. For instance, riparian habitat loss in parts of the US has resulted in the threatened southwestern willow flycatcher (*Empidonax traillii extimus*) becoming increasingly reliant on non-native, invasive tamarisks (*Tamarix* spp) that have largely replaced the native vegetation (Sogge *et al.* 2008; Bean and Dudley 2018), as tamarisks now provide the only dense vegetation suitable for flycatcher nesting. Yet reliance on a resource may also be driven by a species’ preference for novel over traditional resources. In behavioral choice experiments in the Knysna Estuary, South Africa, the endangered Knysna seahorse (*Hippocampus capensis*) preferentially selected novel, artificial habitat (Reno mattresses, which are wire cages filled with rocks) over traditional eelgrass (*Zostera capensis*) habitat (Claassens *et al.* 2018). For some species, the use of novel resources is already influencing species evolutionary responses (Johnson and Munshi-South 2017; Thompson *et al.* 2018), with morphological and/or genetic variations associated with novel resource use observed in Knysna seahorses (larger body sizes; Claassens and Hodgson 2018), Puerto Rican crested anoles (longer limbs and more lamellae; Winchell *et al.* 2016), and great tits (*Parus major*) in the UK (longer bills; Bosse *et al.* 2017). Even so, for most organisms, it is still unclear what the reliance on, preference for, and adaptation to novel resources means for the individual, the species, or the broader community (Figure 4).

Novel resource use may vary depending on the availability of both traditional and novel resources; moreover, species may switch between these resource types. When abundance of traditional food resources was poor in wildland areas in North America, black bears exhibited behavioral plasticity and shifted their behavior to foraging on human garbage in nearby urban areas (Lewis *et al.* 2015). In altered ecological environments, with a blend of novel and traditional resources, the novel resource may influence habitat use (MacClagan *et al.* 2018) and subsequent community composition (Wolf *et al.* 2018). For instance, native rodent-feeding raptors and snakes were more abundant in unrestored Californian grasslands dominated by



**Figure 4.** Schematic diagram outlining the characteristics influencing novel resource use by species, illustrated here by a gray-tailed mountain-gem (*Lampornis cinereicauda*) in Costa Rica feeding on the flower of an introduced ornamental plant, *Callistemon* sp, which is native to Australia (WebFigure 1). Independent traits of both the resource and the species (blue) influence how a species will use a novel resource (yellow). The species reliance on, preference for, and adaptation to the novel resource may also be influenced by the environmental context in which a species uses that novel resource (green), including the relative availability of both novel and traditional resources. These characteristics subsequently influence how a novel resource may impact (negligibly, positively, negatively) an organism at the individual, population, species, and community levels (dark red). Superscripted numbers indicate published examples of these impacts: <sup>1</sup>Lewis *et al.* (2015); <sup>2</sup>Murray *et al.* (2015); <sup>3</sup>Winchell *et al.* (2016); <sup>4</sup>Claassens and Hodgson (2018); <sup>5</sup>Donovan (2015); <sup>6</sup>Bosse *et al.* (2017); <sup>7</sup>Wolf *et al.* (2018); <sup>8</sup>Buettner *et al.* (2013).

exotic annuals that also contained more non-native house mice (*Mus musculus*) than comparable restored grasslands dominated by native perennials but fewer mice (Wolf *et al.* 2018).

Species responses to a novel resource may vary depending on whether the novel resource replaces a traditional resource or provides an alternative, additional resource option. In some circumstances, the availability of a novel resource may lead to an expansion in a species' range or population (eg coyote [*Canis latrans*] in the northern US; Donovan 2015). However, if a novel resource benefits a species by ameliorating human-mediated environmental change (eg by replacing a traditional resource), the species may not exhibit detectable changes at the population scale (eg Becker and Buchholz 2016). In addition, by utilizing a replacement novel resource, a threatened species may possibly reduce the rate of its decline, although documented examples of this scenario are scarce in the scholarly literature. In southwestern Australia, foraging by the endangered Carnaby's cockatoo (*Zanda [Calyptorhynchus] latirostris*; Stock *et al.* 2013) in non-native pine plantations may have partially compensated for losses of its native foraging habitat (*Banksia* woodlands) that was cleared for establishing the pine plantations and by expanding urbanization (Williams *et al.* 2017).

Novel resources may not necessarily be beneficial, and may have negligible or negative impacts on the species using them. Indeed, in some circumstances novel resources may become evolutionary or ecological traps for the species that use them (Robertson *et al.* 2013). Evolutionary traps arise when a species finds a resource just as attractive, if not more so, than other resources, even though the species experiences reduced fitness as a consequence of using the resource (Robertson *et al.* 2013; Singer and Parmesan 2018). For instance, coyote foraging on human food sources has been associated with sarcoptic mange, with likely impacts on reproductive output (Murray *et al.* 2015). Ecological traps are a type of evolutionary trap where a species uses a habitat that reduces fitness, despite other available habitats. In one example from reserves near Chicago, Illinois, American robins (*Turdus migratorius*) preferentially nested in non-native honeysuckle (*Lonicera* sp) shrubs, but experienced higher rates of nest predation than in native shrubs possibly because the architecture of honeysuckles facilitated the movements of mammalian predators (Schmidt and Whelan 1999).

Novel resource use can also impact species by altering community composition (Wolf *et al.* 2018) or by promoting new species interactions (Buettner *et al.* 2013). In the tropical rainforests of northern Australia, foraging by the threatened spectacled flying fox (*Pteropus conspicillatus*) on a novel food source (fruit from the non-native wild tobacco bush, *Solanum mauritianum*), which grows lower to the ground than traditional food sources, increased their exposure to a ground-dwelling ectoparasite (the native Australian paralysis tick, *Ixodes holocyclus*), leading to occasional paralysis in and mortality of flying foxes (Buettner *et al.* 2013).

## ■ Implications for conservation

From a management perspective, it is increasingly important to understand how species, and especially threatened species, use and respond to novel resources. The reliance of species

on novel resources most commonly arises due to recent human actions (indirect or otherwise), and different human actions may add or remove these resources, which could affect management practices and future conservation policy (Figure 5; Panel 2). Species' use of novel resources adds a further layer of complexity to conservation and management decisions. For the most part, how effective novel resources are in realizing desired conservation outcomes for focal threatened species remains unclear, but as conservation planning starts including novel resources in efforts to satisfy species' resource requirements, a better understanding of this relationship is needed (Panel 2). This may be particularly relevant in markedly altered environments, such as cities, where threatened species persist (Soanes and Lentini 2019).

In environments with high ecosystem novelty, novel resources may provide analogous resource replacements (eg substrate, food; Becker and Buchholz 2016; Caballero *et al.* 2016) that ameliorate the effects of lost native resources. Indeed, the addition of novel resources may be an important management tool for some threatened species. For example, nest boxes are often used as a means to entice tree-cavity-dependent fauna (eg arboreal mammals; Goldingay *et al.* 2015) to remain in or return to altered landscapes; likewise, threatened European ocellated lizards (*Timon lepidus*) readily occupy artificial refuges that mimic their traditional refuge – burrows of the European rabbit (*Oryctolagus cuniculus*) – when supplied (Grillet *et al.* 2010). Furthermore, human-created artificial structures may provide critical habitat for a subset of threatened species that use them (Garcia-Gomez *et al.* 2011; Wallace *et al.* 2016); there is growing interest in the ecological value of retaining inactive offshore petroleum and natural gas platforms to provide novel structures for the marine communities that have colonized them (van Elden *et al.* 2019).

If a species becomes reliant on a novel resource, there is always the risk that changes in human actions (which initially provided or facilitated use of the resource) may subsequently remove that resource. For instance, a population of Edith's checkerspot (*Euphydryas editha*), a butterfly species endemic to North America, shifted foraging from its traditional native plant resource (*Collinsia parviflora*) to the non-native *Plantago lanceolata*, the abundance of which increased under grazing management practices. However, cessation of livestock grazing altered the microhabitat's thermal conditions required by the butterfly to survive on *P lanceolata*, leading to its extirpation (local extinction) despite the presence of its traditional plant resource (Singer and Parmesan 2018). This finding demonstrates that in some cases species may lose the ability to switch back to their traditional resource, thereby ensuring their near complete dependence on the novel resource. Another instance illustrating the management complications associated with a threatened species' reliance on a novel resource is the controversy surrounding the biocontrol of non-native, invasive tamarisk shrubs in the US (Bean and Dudley 2018). As discussed above, the threatened southwestern willow flycatcher successfully nests within tamarisks (Sogge *et al.* 2008), and removal of these invasive shrubs will further imperil this avian species.



## Panel 2. Conservation and management implications of novel resources: Carnaby's cockatoo and pine plantations

Carnaby's cockatoo (*Zanda [Calyptorhynchus] latirostris*; Figure 5), a long-lived, migratory parrot endemic to southwestern Australia, is threatened by historical and ongoing loss of nesting and foraging habitat. One of the largest populations of this seed-eating parrot forages and roosts in extensive non-native pine plantations (>20,000 ha at largest extent, predominantly composed of maritime pine [*Pinus pinaster*]) near the city of Perth, and has done so for ~75 years (Stock *et al.* 2013). However, the parrots also still utilize traditional food resources (seeds of *Banksia* spp and other species) throughout the remnant native woodland. The pine plantations are being harvested commercially and to increase groundwater recharge to address water-resource needs for the human population of Perth in a drying climate (Government of Western Australia 2015). At the same time, there is ongoing removal of the native *Banksia* woodlands due to expanding urbanization. Coupled with historical and ongoing declines in breeding habitat elsewhere, the population of Carnaby's cockatoo in the Perth region is projected to decline by 34–56% by 2050 as a result of these changes (Williams *et al.* 2017), and the cockatoos are now considered reliant on the pine as a food resource (Stock *et al.* 2013). A conservation mitigation strategy being deployed involves replanting 5000 ha of pine specifically for Carnaby's cockatoo (Government of Western Australia 2015). Replanting with pines is more cost-effective than replanting *Banksia* woodlands (Government of Western Australia 2015), and pines provide more calorific value (per cone) than the cones of native *Banksia* spp (Stock *et al.* 2013). However, there are very few other conservation values associated with replanting pine plantations. Furthermore, this management decision relies on several assumptions, including that pinecone seeds provide equivalent nutritional requirements to Carnaby's cockatoos and that consumption of pinecone seeds has no detrimental effects to the birds' long-term survival. This information is currently lacking, but urgently needed if managers are to better understand the impacts of this threatened species using a novel resource.



**Figure 5.** In southwestern Australia, (a) non-native pine plantations are considered as (b) novel food resources and roosting sites for the endangered Carnaby's cockatoo (*Zanda [Calyptorhynchus] latirostris*).

Consequently, biocontrol programs have been excluded from areas where the flycatcher utilizes tamarisks (Bean and Dudley 2018). Thus, nuanced management approaches not only may be required where threatened species rely on novel resources but also may be particularly important when existing management practices or policies target the removal of the novel resource (eg because it is a non-native, invasive species). Conversely, if a novel resource has detrimental effects on a species, or on the broader ecological community, management strategies may require direct human intervention to remove the novel resource (ideally replacing it with a traditional resource, although in many modified environments this may be challenging).

The rate and scale at which humans have altered the natural world has resulted in the exposure and mixing of previously unaffiliated groups of species and habitats. Here, we explored several cases of novel resource use by focal species, highlighting that novel resources may both provide opportunities and incur costs for the species that use them. The broader ecological consequences of novel resource use by species are still largely

unknown. Frameworks for addressing novelty in a management context are evolving (Hobbs *et al.* 2014, 2018; Schlappy and Hobbs 2019), as is the need to consider novel resources as a potentially important element of threatened species habitat. Given the species-specific nature of novel resources, it is challenging to predict how taxa will use and adapt to them, and whether their responses will be positive, negative, or neutral at the individual, species, or community level. However, by being aware of the diverse ways that species use and respond to novel resources, managers may be able to incorporate this information in ongoing and future conservation plans. Given the degree of anthropogenic change, the uptake and potential reliance of novel resources by species is only likely to increase.

### ■ Acknowledgements

Financial support was provided by the Australian Government's National Environmental Science Program through the Threatened Species Recovery Hub and the Clean

Air and Urban Landscapes Hub, and the Australian Research Council Linkage Grant LP0882687.

## References

- Aplin KP, Suzuki H, Chinen AA, *et al.* 2011. Multiple geographic origins of commensalism and complex dispersal history of black rats. *PLoS ONE* **6**: e26357.
- Bean DW and Dudley TL. 2018. A synoptic review of *Tamarix* bio-control in North America: tracking success in the midst of controversy. *BioControl* **63**: 361–76.
- Becker M and Buchholz S. 2016. The sand lizard moves downtown – habitat analogues for an endangered species in a metropolitan area. *Urban Ecosyst* **19**: 361–72.
- Bosse M, Spurgin LG, Laine VN, *et al.* 2017. Recent natural selection causes adaptive evolution of an avian polygenic trait. *Science* **358**: 365–68.
- Buettner PG, Westcott DA, Maclean J, *et al.* 2013. Tick paralysis in spectacled flying foxes (*Pteropus conspicillatus*) in north Queensland, Australia: impact of a ground-dwelling ectoparasite finding an arboreal host. *PLoS ONE* **8**: e73078.
- Caballero IC, Bates JM, Hennen M, and Ashley MV. 2016. Sex in the city: breeding behaviour of urban peregrine falcons in the mid-western US. *PLoS ONE* **11**: e0159054.
- Claassens L and Hodgson AN. 2018. Monthly population density and structure patterns of an endangered seahorse *Hippocampus capensis*: a comparison between natural and artificial habitats. *J Fish Biol* **92**: 2000–15.
- Claassens L, Booth AJ, and Hodgson AN. 2018. An endangered seahorse selectively chooses an artificial structure. *Environ Biol Fish* **101**: 723–33.
- Cox DT and Gaston KJ. 2018. Human–nature interactions and the consequences and drivers of provisioning wildlife. *Philos T Roy Soc B* **373**: 20170092.
- Dennis RL, Shreeve TG, and Van Dyck H. 2003. Towards a functional resource-based concept for habitat: a butterfly biology viewpoint. *Oikos* **102**: 417–26.
- Donovan T. 2015. Feral cities: adventures with animals in the urban jungle. Chicago, IL: Chicago Review Press.
- Fleming PA and Bateman PW. 2018. Novel predation opportunities in anthropogenic landscapes. *Anim Behav* **138**: 145–55.
- Garcia-Gomez JC, Lopez-Fe CM, Espinosa F, *et al.* 2011. Marine artificial micro-reserves: a possibility for conservation of endangered species living on artificial substrata. *Mar Ecol* **32**: 6–14.
- Goldingay RL, Rueegger NN, Grimson MJ, and Taylor BD. 2015. Specific nest box designs can improve habitat restoration for cavity-dependent arboreal mammals. *Restor Ecol* **23**: 482–90.
- Government of Western Australia. 2015. Perth and Peel Green Growth Plan for 3.5 million. Perth, Australia: WA Government.
- Grillet P, Cheylan M, Thirion J, *et al.* 2010. Rabbit burrows or artificial refuges are a critical habitat component for the threatened lizard, *Timon lepidus* (Sauria, Lacertidae). *Biodivers Conserv* **19**: 2039–51.
- Guerra-Garcia JM, Corzo J, Espinosa F, and Garcia-Gomez JC. 2004. Assessing habitat use of the endangered marine mollusc *Patella ferruginea* (Gastropoda, Patellidae) in northern Africa: preliminary results and implications for conservation. *Biol Conserv* **116**: 319–26.
- Heger T, Bernard-Verdier M, Gessler A, *et al.* 2019. Towards an integrative, eco-evolutionary understanding of ecological novelty: studying and communicating interlinked effects of global change. *BioScience* **69**: 888–99.
- Hobbs RJ, Higgs ES, and Hall CM (Eds). 2013. Novel ecosystems: intervening in the new ecological world order. West Sussex, UK: John Wiley & Sons.
- Hobbs RJ, Higgs ES, and Harris JA. 2009. Novel ecosystems: implications for conservation and restoration. *Trends Ecol Evol* **24**: 599–605.
- Hobbs RJ, Valentine LE, Standish RJ, and Jackson ST. 2018. Movers and stayers: novel assemblages in changing environments. *Trends Ecol Evol* **33**: 116–28.
- Hobbs RJ, Higgs ES, Hall CM, *et al.* 2014. Managing the whole landscape: historical, hybrid, and novel ecosystems. *Front Ecol Environ* **12**: 557–64.
- Jeffries MJ and Lawton JH. 1984. Enemy free space and the structure of ecological communities. *Biol J Linnean Soc* **23**: 269–86.
- Johnson MTJ and Munshi-South J. 2017. Evolution of life in urban environments. *Science* **358**: eaam8327.
- Johnstone RE, Kirkby T, and Sarti K. 2017. The distribution, status, movements and diet of the forest red-tailed black cockatoo in the south-west with emphasis on the greater Perth region, Western Australia. *Western Austral Nat* **30**: 193–219.
- Kennedy PL, Lach L, Lugo AE, and Hobbs RJ. 2013. Fauna and novel ecosystems. In: Hobbs RJ, Higgs ES, and Hall CM (Eds). Novel ecosystems: intervening in the new ecological world order. West Sussex, UK: John Wiley & Sons.
- Kennedy PL, Fontaine JB, Hobbs RJ, *et al.* 2018. Do novel ecosystems provide habitat value for wildlife? Revisiting the physiognomy vs floristics debate. *Ecosphere* **9**: e02172.
- LaPoint SD, Belant JL, and Kays RW. 2015. Mesopredator release facilitates range expansion in fisher. *Anim Conserv* **18**: 50–61.
- Lewis DL, Baruch-Mordo S, Wilson KR, *et al.* 2015. Foraging ecology of black bears in urban environments: guidance for human–bear conflict mitigation. *Ecosphere* **6**: 141.
- MacClagan SJ, Coates TD, and Ritchie EG. 2018. Don't judge habitat on its novelty: assessing the value of novel habitats for an endangered mammal in a peri-urban landscape. *Biol Conserv* **223**: 11–18.
- MacIvor JS, Roberto AN, Sodhi DS, *et al.* 2017. Honey bees are the dominant diurnal pollinator of native milkweed in a large urban park. *Ecol Evol* **7**: 8456–62.
- Mata L, Ives CD, Moran-Ordóñez A, *et al.* 2016. The little things that run the city – insect ecology, biodiversity and conservation in the City of Melbourne. Melbourne, Australia: City of Melbourne.
- Moreira F, Martins RC, Catry I, and D'Amico M. 2018. Drivers of power line use by white storks: a case study of birds nesting on anthropogenic structures. *J Appl Ecol* **55**: 2263–73.
- Morse NB, Pellissier PA, Cianciola EN, *et al.* 2014. Novel ecosystems in the Anthropocene: a revision of the novel ecosystem concept for pragmatic applications. *Ecol Soc* **19**: art12.
- Murray M, Edwards MA, Abercrombie B, and St Clair CC. 2015. Poor health is associated with use of anthropogenic resources in an urban carnivore. *P Roy Soc B-Biol Sci* **282**: 20150009.
- Newsome TM, Dellinger JA, Pavey CR, *et al.* 2015. The ecological effects of providing resource subsidies to predators. *Global Ecol Biogeogr* **24**: 1–11.



- Ortega Y, Greenwood LE, Callaway RM, and Pearson DE. 2014. Different responses of congeneric consumers to an exotic food resource: who gets the novel resource prize? *Biol Invasions* **16**: 1757–67.
- Packer JG, Delean S, Kueffer C, *et al.* 2016. Native faunal communities depend on habitat from non-native plants in novel but not in natural ecosystems. *Biodivers Conserv* **25**: 503–23.
- Parris KM and Hazell DL. 2005. Biotic effects of climate change in urban environments: the case of the grey-headed flying-fox (*Pteropus poliocephalus*) in Melbourne, Australia. *Biol Conserv* **124**: 267.
- Price MR, Lee VA, and Hayes WK. 2011. Population status, habitat dependence, and reproductive ecology of Bahama oriole: a critically endangered synanthropic species. *J Field Ornithol* **825**: 366–78.
- Radeloff VC, Williams JW, Bateman BL, *et al.* 2015. The rise of novelty in ecosystems. *Ecol Appl* **25**: 2051–68.
- Robertson BA, Rehage JS, and Sih A. 2013. Ecological novelty and the emergence of evolutionary traps. *Trends Ecol Evol* **28**: 552–60.
- Schlappy M-L and Hobbs RJ. 2019. A triage framework for managing novel, hybrid and designed marine ecosystems. *Glob Change Biol* **25**: 3215–23.
- Schmidt KA and Whelan CJ. 1999. Effects of exotic *Lonicera* and *Rhamnus* on songbird nest predation. *Conserv Biol* **13**: 1502–06.
- Singer MC and Parmesan C. 2018. Lethal trap created by adaptive evolutionary response to an exotic resource. *Nature* **557**: 238–41.
- Soanes K and Lentini PE. 2019. When cities are the last chance for saving species. *Front Ecol Environ* **17**: 225–31.
- Sogge MK, Sferra SJ, and Paxton EH. 2008. *Tamarix* as habitat for birds: implications for riparian restoration in the southwestern United States. *Restor Ecol* **16**: 146–54.
- Sol D, Griffin AS, Bartomeus I, and Boyce H. 2011. Exploring or avoiding novel food resources? The novelty conflict in an invasive bird. *PLoS ONE* **6**: e19535.
- Starkey A and delBarco-Trillo J. 2019. Supplementary feeding can attract red squirrels (*Sciurus vulgaris*) to optimal environments. *Mamm Biol* **94**: 134–39.
- Steffen W, Broadgate W, Deutsch L, *et al.* 2015. The trajectory of the Anthropocene: the Great Acceleration. *Anthropocene Rev* **2**: 81–98.
- Stock WD, Finn H, Parker J, and Dods K. 2013. Pine as fast food: foraging ecology of an endangered cockatoo in a forestry landscape. *PLoS ONE* **8**: e61145.
- Thompson KA, Rieseberg LH, and Schluter D. 2018. Speciation and the city. *Trends Ecol Evol* **33**: 815–26.
- van Elden S, Meeuwij JJ, Hobbs RJ, and Hemmi JM. 2019. Offshore oil and gas platforms as novel ecosystems: a global perspective. *Front Mar Sci* **6**: 548.
- Vitousek PM, Mooney HA, Lubchenco J, and Melillo JM. 1997. Human domination of Earth's ecosystems. *Science* **277**: 494–99.
- Wallace Z, Kennedy PL, Squires JR, *et al.* 2016. Human-made structures, vegetation and weather influence ferruginous hawk breeding performance. *J Wildlife Manage* **80**: 78–90.
- Williams MR, Yates CJ, Saunders DA, *et al.* 2017. Combined demographic and resource models quantify the effects of potential land-use change on the endangered Carnaby's cockatoo (*Calyptorhynchus latirostris*). *Biol Conserv* **210**: 8–15.
- Winchell KM, Reynolds RG, Prado-Irwin SR, *et al.* 2016. Phenotypic shifts in urban areas in the tropical lizard *Anolis cristatellus*. *Evolution* **70**: 1009–22.
- Wolf KM, Whalen MA, Bourbour RP, and Baldwin RA. 2018. Rodent, snake and raptor use of restored native perennial grasslands is lower than use of unrestored exotic annual grasslands. *J Appl Ecol* **55**: 1133–44.

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