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.

**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...
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 (e.g., 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 (e.g., resource availability) that may determine whether (and how) a species uses a novel resource. The suite of characteristics (e.g., structures, species, processes) associated with an ecosystem.

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.
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 (Calyptrorhynchus 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 (e.g. human garbage, bird feeders; Newsome et al. 2015; Cox and Gaston 2018).

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 (e.g. breeding, feeding, thermoregulation, shelter, dispersal), whereas utility resources include the environmental conditions required for development, persistence, and survival (e.g. 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 (e.g. 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.

Figure 2. Images of species that use novel resources (from Figure 1), including (a) forest red-tailed black cockatoos (Calyptrorhynchus 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.

How do species use novel resources?

For instance, red eucalyptus trees (Eucalyptus globulus) 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 (e.g. 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.
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 (e.g., 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 (e.g., health; Murray et al. 2015), population dynamics (e.g., 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 (e.g., 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 (Rennomat tires, 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 adaption 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 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).

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: 1Lewis et al. (2015); 2Murray et al. (2015); 3Winchell et al. (2016); 4Claassens and Hodgson (2018); 5Donovan (2015); 6Bosse et al. (2017); 7Wolf et al. (2018); 8Buettner et al. (2013).
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 [Calyptrorychus] 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 checkerspots (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.
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 (e.g., 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.

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**Supporting Information**

Additional, web-only material may be found in the online version of this article at [http://onlinelibrary.wiley.com/doi/10.1002/fee.2255/suppinfo](http://onlinelibrary.wiley.com/doi/10.1002/fee.2255/suppinfo)

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**Going walkabout**

Koalas (*Phascolarctos cinereus*) famously spend most of their lives in *Eucalyptus* trees. However, in December 2018, this koala stumbled across Australia’s only mainland gannet (*Morus serrator*) colony near the city of Portland, in what is believed to be the first documented encounter between these species. Local habitat loss could have driven the koala to any unusual location, but why exactly it chose to explore a seabird colony 14 kilometers from the nearest *Eucalyptus* forest will likely remain a mystery.

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