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Opinion

Valuing the contributions of non-native species to people and nature

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While decision-making can benefit from considering positive and negative outcomes of change, over the past half-century, research on non-native species has focused predominately on their negative impacts. Here we provide a framework for considering the positive consequences of non-native species relative to relational, instrumental, and intrinsic values. We demonstrate that their beneficial outcomes are common and profoundly important for human well-being. Identified benefits include social cohesion, cultural identity, mental health, food and fuel production, regulation of clean waters, and attenuation of climate change. We argue that long-standing biases against non-native species within the literature have clouded the scientific process and hampered policy advances and sound public understanding. Future research should consider both costs and benefits of non-native species.

Highlights

The study of non-native species has predominantly focused on quantifying the costs they inflict on people and nature.

Recent decades have witnessed scientists acknowledging, and over the past few years increasingly investigating, the benefits that non-native species may provide.

Here we provide a framework for considering the diversity of positive benefits supported by non-native species relative to relational, instrumental, and intrinsic values.

Despite undoubted publication biases, we find that benefits of non-native species are diverse, frequent, and often of large magnitude.

More research aimed at considering benefits of non-native species, and contrasting these benefits with costs is needed to advance our understanding of the impacts of non-native species and better contextualize management and policy decisions.

The perceived value of non-native species

The perceived value of **non-native species** (see Glossary) has varied tremendously over human history. During the 18th through early 20th centuries, non-native species were prized for their instrumental value and actively introduced around the world to provide sources of food, fuel, and materials [1,2]. Shifting sentiments were punctuated by the publication of Charles Elton's [3] seminal work on invasions, which framed introduced species as a stark threat to human interests. Since that time, the majority of research on non-native species has focused on their negative consequences (e.g., [4,5]). In recent decades, a few studies have pointed out the necessity to also investigate the potential positive contributions of non-native species [6–9] and recently some have explicitly considered both their positive and negative impacts [10–12].

While some non-native species clearly generate overwhelming benefits or overwhelming costs to people and nature, the net consequences of most non-native species is less certain. Most domesticated species, which are found widely outside their native regions of origin, provide large net benefits to human societies. Indeed, these species are woven into the very fabric of human civilization: from the food we grow, like wheat and tomatoes, to the fiber we produce, including cotton and wool, to the pets we keep, such as dogs and goldfish. Other species, such as introduced pathogens and agricultural pests, provide large net costs. In contrast to these straightforward examples, most non-natives have both positive and negative effects that manifest across different types of values (relational, instrumental, intrinsic), vary in space and time, and have diverse relevance to different stakeholders. For example, non-native species can be a leading cause of species extinctions [13], but also contribute, through their own immigration, to regional biodiversity [14]; they can reduce certain ecosystem functions, such as water clarity [15], while increasing others, such as erosion control [16]; they can remove an important resource, such as American chestnuts (*Castanea dentata*) [17], while providing new resources, such as recreational hunting and fishing opportunities [18]. Indeed, both costs and benefits from non-native species are probably more common than previously assumed [11,19].

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For example, close to half of non-native species (44 out of 102) examined [11] (Figure 1) and three-quarters of non-native marine species (63 out of 87) in European waters had both positive and negative effects on biodiversity and ecosystem functions [20].

To gain a holistic understanding of any complex issue, one must consider both the positive and negative aspects of the question at hand. One only needs to look at growing partisanship in politics, such as debates currently focused on human immigration or a clean energy transition, to appreciate how a narrow-minded focus on the costs of a complex policy decision (that ignores the benefits) can lead to short-sighted and potentially erroneous decisions. With respect to non-native species, basic book-keeping requires that both sides of the ledger be considered. Failure to do so could lead to misguided management and policy decisions and misleading messaging to the public. Examples of misguided policy could include investing resources in removal or eradication of non-natives that are unwarranted relative to the net benefits they provide or failure to protect non-natives that are providing important benefits to particular stakeholder groups. Unfortunately, the data necessary for objective assessments of many non-native species remain wanting, as the predominant focus of investigation has been on their negative impacts [9,21]. We suspect this implicit focus on negative impacts is due, at least in part, to a failure by some scientists to appreciate, and thus study, the diverse ways that non-native species offer benefits to society. Indeed, while there are many individual stakeholder groups who value particular non-native species (e.g., anglers who value non-native fish introductions [18]), we believe that the frequent, important, and diverse ways that non-native species provide value are not generally appreciated. This scientific gap is due to a variety of factors, but paramount among these are both a dearth of attention on positive value provided by non-natives and the lack of a topology or framework for considering the diverse ways these values manifest for people and nature.

Here we explicitly call for a more exhaustive and systematically structured consideration of the positive values supported by non-native species. Because the net benefits of managed populations of non-native species (such as wheat and tomatoes) are so large, we do not consider them further here. Instead, we focus on species with unmanaged, non-native populations (i.e., species that have populations that persist beyond their native range in the absence of active human management); such species are often referred to as being **naturalized species** or **invasive species**, but hereafter we will refer to these unmanaged populations as 'non-native species'. We utilize the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) framework that describes a comprehensive range of nature-based values [22], including intrinsic, instrumental, and relational values. We posit that this framework provides a useful topology for considering the diverse array of ways that non-natives provide value and use this framework here to illustrate representative, but not exhaustive, examples of these values from diverse ecosystems and regions (Table 1). We further use these examples to discuss economic benefits generated by non-native species (Box 1), as these positive economic impacts continue to be largely underappreciated [23]. We also discuss how normative values often associated with the fields of conservation and invasion biology have helped to shape a narrow focus on negative impacts (Box 2). We conclude by considering key information gaps and argue for new research and data initiatives that acknowledge alternative normative views and advance a more balanced study of non-native species in the future.

Relational value

Relational values include those values that arise from people's relationships with nature [24], including national, regional, and cultural identity, cultural mythologies, ways of life, social cohesion, mental health, and recreation. Non-native species' contributions to identity can be seen nationally,

Glossary

Invasive species: the subset of naturalized species that are perceived to be problematic in some way, because they have spread widely or because they have negative economic impacts, harm human health, or negatively impact native species or ecosystems.
Naturalized species: the subset of non-native species that have established self-perpetuating populations and are not dependent on human management to persist.
Non-native species: species introduced by humans outside their native range; this includes species managed by humans (such as agricultural crops) and species that are naturalized or otherwise occur without active human management.

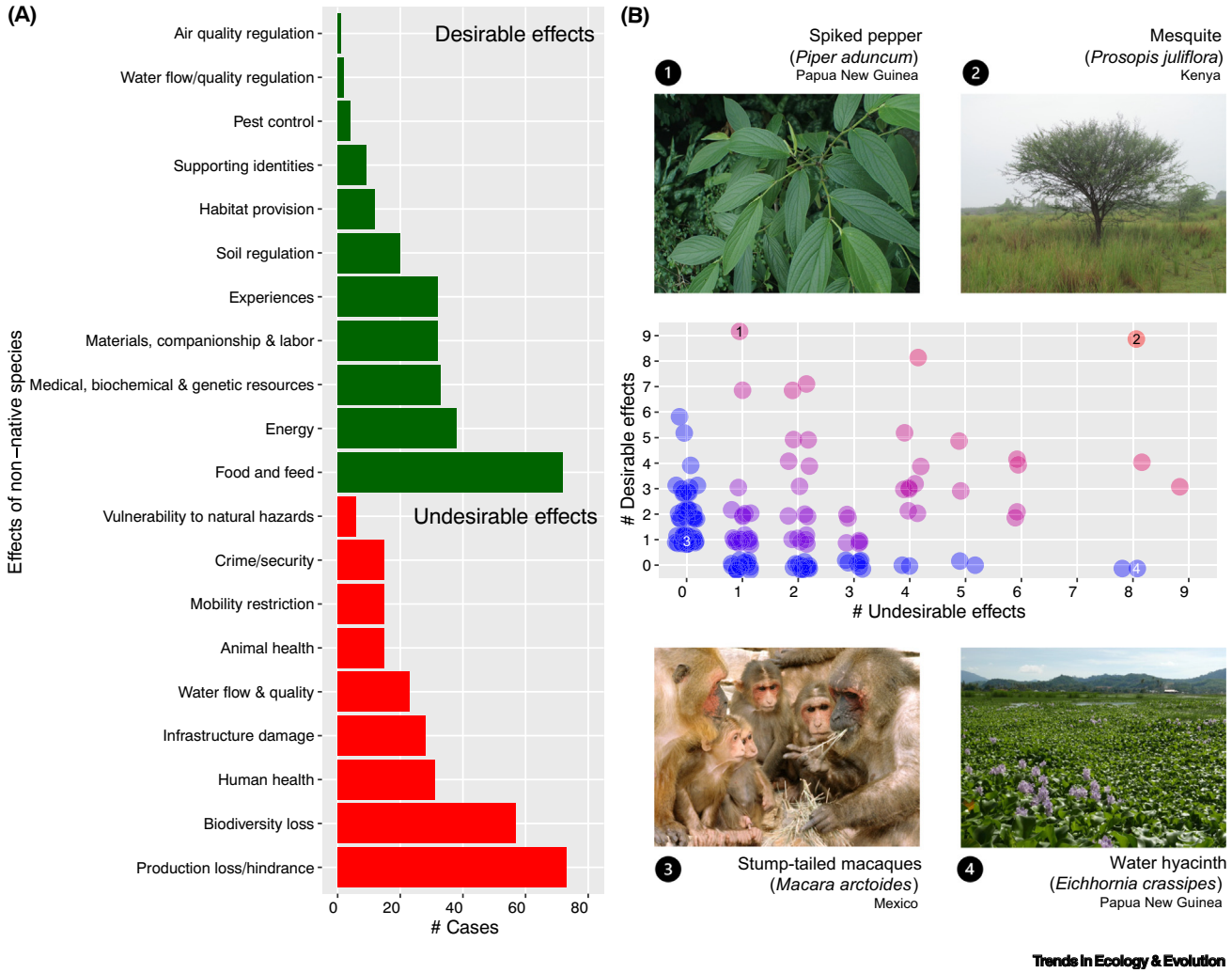

Figure 1. Local communities' perceptions of the desirable and undesirable effects of non-native species in socio-ecological production landscapes and seascapes as reported by Kelsch *et al*. [11]. (A) Total number of reported positive and negative effects of non-native species organized according to categories of regulating, material, or non-material impacts (n = 151 cases for 102 species, where species can have multiple effects). (B) Number of desirable versus undesirable effects of non-native species, demonstrating numerous instances of species having both effects in a particular location (non-blue symbols). Examples include: (1) spiked pepper is widely used for fencing, building structures, farming practices, and its ashes are used as a pesticide in Papua New Guinea; (2) mesquite is considered a globally invasive species with significant ecological impacts, yet concurrently is an important source of fuel, food, fodder, and medicine in many arid regions of the world, including this example from Kenya; (3) stump-tailed macaques have been reported to provide tourism income in Mexico; and (4) water hyacinth is globally distributed, appears on the International Union for Conservation of Nature's (IUCN) list of the world's top 100 most invasive species, and had no instances of substantial benefits reported where it is introduced in Papua New Guinea [11]. All photos are licensed for use under Creative Commons.

with the coat of arms of Mauritius, which features an introduced deer (*Cervus timorensis*), and regionally, for instance, in the US state Kentucky, which self-identifies as the 'Bluegrass State', after an introduced species of grass (*Poa pratensis*). Deep cultural connections to non-native species can form quickly, as evinced by the value of wild donkeys (*Equus asinus*) to people in St John, US Virgin Islands [25]. Likewise, in South Africa numerous plant species, including jacaranda (*Jacaranda mimosifolia*), Chinaberry tree (*Melia azedarach*), and yellow trumpetbush (*Tecoma stans*), have been fully assimilated into the way of life and culture of arid farming settlements, where residents have given non-native species unique local names and several species are not differentiated by residents from native biodiversity [10]. Such a situation is not unusual

Table 1. Select examples of non-native species providing relational, instrumental, and intrinsic value[a]

Foci of value	Types of values	Examples	Specific cases with non-native species
Quality of life	Relational	Cultural identity Cultural mythology Ways of life Recreational hunting and fishing	Deer (*Cervus timorensis*) in Mauritius, bluegrass (*Poa pratensis*) in Kentucky Aboriginal mythology involving dingos (*Canis familiaris dingo*) in Australia Hunting rusa deer (*C. timorensis*) in New Guinea Pheasant (*Phasianus colchicus*) in USA, trout (*Salmo trutta*) in New Zealand
Nature's contribution to people	Instrumental: provisioning	Food Livestock feed Fuel wood and materials	Crayfish (*Procambarus clarkii*) in China, carp (*Cyprinus carpio*) in Kenya Pasture grasses (*Megathyrsus maximus*) in North and South America Chinaberry (*Melia azedarach*) in South Africa, mesquite (*Prosopis juliflora*) in Ethiopia
	Instrumental: regulatory	Agricultural productivity Biological control Clean water Erosion control Habitat creation and maintenance Pollination Propagule dispersal Climate regulation	Earthworms (*Lumbricus terrestris*) in Midwestern USA Biocontrol of cassava (*Manihot esculenta*) pests in Africa by *Apoanagyrus lopezi* Removal of pollutants in marshes by *Phragmites australis* in USA Erosion control of coastal habitat with the introduced plant (*Carex kobomugi*) in USA *Eucalyptus* trees provide habitat for monarch butterflies (*Danaus plexippus*) in USA Pollination by bumblebees (*Bombus terrestris*) in Chile Seed dispersal by blackbird (*Turdus merula*) in New Zealand Carbon sequestration by seagrass (*Halophila stipulacea*) in the Mediterranean Sea
Nature	Intrinsic	Animal welfare/rights Ecological and evolutionary processes Species diversity	Public concern over eradication efforts, wild horses (*Equus ferus*) in USA Novel species interactions globally, new species creation in UK Increased plant and freshwater fish diversity at subglobal scales

[a]All the types of value commonly ascribed to biological diversity are provided by non-native species. Table modeled after IPBES evaluation [22]. See text for references.

and other researchers have found that local residents often do not distinguish 'adopted' non-native species from the indigenous vegetation [26].

Over longer time periods, non-native species can become deeply integrated culturally, as is the case with the integration of the dingo (*Canis familiaris dingo*), introduced to Australia ca. 3500 ybp, into mythologies and ways of life of Aboriginal peoples in Australia [27]. Traditional hunting practices, which are important for social cohesion, are often based around non-native species, such as introduced deer (*C. timorensis*) in New Guinea [28] and feral pigs (*Sus scrofa*) in Hawaii [29]. Recreational hunting and fishing activities have also been shown to coincide with mental and emotional health [30,31] and these are often based around non-native species; this includes various species like deer, pigs, pheasants (*Phasianus colchicus*), trout (*Salmo trutta*), salmon (*Oncorhynchus tshawytscha*), bass, and others [28,29,32,33]). In many places, the value provided by these non-native species is recognized, such that laws and policies have been enacted to maintain viable, long-term populations; key examples include introduced salmonid fishes in New Zealand and introduced game species in the USA [32,33]. Although the aforementioned examples show that the relational value of non-native is positive and widespread for many people and in many places around the world, these same examples could be viewed by individuals with strong normative values oriented around 'nativism' as providing negative relational values as well (Box 2).

Instrumental value

Non-native species were often introduced specifically for their perceived instrumental value to society, so it should not be surprising that, as a group, these species contribute many of these benefits to people. Here we discuss instrumental value relative to provisioning of resources and regulatory services.

Box 1. Economic value of non-native species

Here we draw attention to the economic benefits associated with the instrumental value provided by non-native species, focusing specifically upon provisioned resources and regulatory services.

Provisioned resources associated with non-native species frequently provide economic value. For example, countless non-native fishes are critical components of subsistence, small-scale, and commercial fisheries that contribute towards regional economies and food security, as in numerous African countries [34,60]. Indeed, in some places the only viable commercial fisheries are based upon non-native species of fish [34]. Likewise, there are substantial economic benefits associated with recreational fishing. For example, black basses (*Micropterus* spp.) consistently are considered among the most popular recreational freshwater fish and were overwhelmingly viewed as an economic advantage in a survey of fisheries biologists across the USA [61], despite their well-recognized ecological impacts [18]. Similarly, the non-native salmonid fishery in New Zealand produces substantial economic benefits [62], as do fisheries with non-native species in the Mediterranean Sea [12]. At present, however, there has been no general effort to estimate or catalog the positive economic impacts of provisioned resources provided by non-native species. These economic benefits are large (e.g., in some cases individual non-native fisheries support the economies of more than a million people) [34], but detailed tallies of these benefits remain wanting. Instead, several major reviews have focused solely on tallies of their economic costs [5,63].

As with provisioned services, the positive economic benefits of regulatory services provided by non-native species have been understudied. While estimates of specific economic benefits have been estimated in some cases (e.g., upwards of US$ 1000 in protection per dollar spent on biological control to protect urban *Eucalyptus* trees in California from introduced pests [45]), in most cases such estimates are not available. These economic benefits, however, are likely to be tremendously large in some cases. Indeed, whole regional agricultural industries, such as citrus production in California, are enabled because of the introduction of non-native species acting as biological control agents [44,64]. Likewise, introduced earthworms that greatly increase agricultural productivity, by an average of 25% [42], are necessarily providing large economic benefits, particularly given the important role of agricultural production for the global economy.

This lack of attention in the literature to the positive economic value provided by non-native species leads to critical questions about the relative cost–benefit ratio of both individual non-native species and this group as a whole (see Outstanding questions).

Provisioning of resources

Non-native species were often historically introduced for the provisioned resources they provided and these uses continue to the present day. Unmanaged populations of non-native species provide food in many parts of the world, from red swamp crayfish (*Procambarus clarkii*) in China, to fish in Kenya, to deer in Mauritius and New Guinea [28,34–36]. Feed for domesticated livestock is also provided by non-native species, such as introduced pasture grasses in many regions of the world [37]. In northeastern Brazil, the vast majority of invasive plant species (55 out of 56 species) were identified in local communities as being useful for animal feed, medicine, or food [38]. Energy and materials can also be provided by non-native species, such as with firewood and building materials provided by non-native tree species, such as Chinaberry trees in South Africa [10] and mesquite (*Prosopis juliflora*) in Ethiopia [39]. Ultimately, provisioning of resources is likely one of the most frequent benefits provided by non-native species. Further, these provisioned resources also provide economic value.

Regulatory services

Non-native species provide a diverse array of regulatory services of value to humans and natural ecosystems. For instance, non-native plants are known to be effective regulators of waterborne pollutants and in some cases may be more effective at regulating pollutants than native species [40]. Similarly, non-native species are used extensively for erosion control and in some cases provide this function better than native species [16] or in the absence of native habitat [41]. Non-native species, such as earthworms (*Lumbricus terrestris*), can be important in regulating agricultural production, increasing agricultural yields by an average of 25% [42]. This is particularly important in agricultural systems where earthworms did not occur historically (e.g., much of the Midwestern USA). Non-native earthworms can be important even when native earthworm species occur (e.g., pasture productivity in New Zealand increases when non-native earthworms

Box 2. Normative values in conservation and invasion biology

There is little disagreement that non-native species can cause profound change in ecological systems. Whether or not individual changes are 'harmful', however, is not determined by scientific evidence alone, but instead by a conjunction of data and normative values. For instance, we can imagine that an introduced plant that stabilizes dunes might be viewed positively by some (for reducing coastal flooding), but negatively by others (for displacing native species). Normative values have shaped the fields of conservation and invasion biology, which have had significant impacts on how changes caused by non-native species are perceived. Conservation biology, particularly in the USA, has historically focused on preserving 'natural' landscapes: those perceived as little changed by human impacts. Similarly, much of the field of invasion biology has historically focused on predicting, documenting, and managing the changes caused by non-native species [65]. Indeed, conservation biologists often apply a normative framework in which non-native species, and any change they cause, are defined as harmful *per se* [66]. Under such a normative perspective 'displacing native species' is harmful, even in the absence of significant changes in species richness or ecosystem services. For some researchers, eliminating non-native species and limiting their impacts may even represent a moral imperative [67].

Worldviews in which humans are viewed as a separate entity from nature are sometimes described as 'dualistic'. 'Nativism' is an example of a dualistic worldview that favors native biodiversity because it holds an ideal of a wild nature unaltered by humans. It therefore also discounts the intrinsic, relational, or instrumental values associated with non-native species. Although nativist positions remain a minority position within conservation sciences [54], global biodiversity indicators still carry the imprint of these values [29]. For example, it is not uncommon to see forecasts of biodiversity that exclude non-native species (e.g., [68]) or reports that describe ecosystems dominated by non-native species as being 'devoid of life' and with 'nothing to see' [69] or the 'scourge of conservation' [70]. In this context, it is perhaps not surprising that the regional IUCN Red List does not integrate introduced populations into their calculation of species' extinction risk [29]. Of course, worldviews shape many other issues in conservation, such as the value of ecosystems with novel assemblages of species [71], and so these issues have broad significance beyond considerations of non-native species. Going forward, we hope that scientists will become better versed at recognizing indicators or data that have been shaped by normative stances and no longer present them as if they were objective, value-neutral, and therefore 'truthful'.

are present) [43]. Non-native species are also used to conduct biological control of a wide variety of pest species, which explicitly uses benefits provided by one group of non-natives to offset the costs of another; examples include biological control by non-natives that enable production of citrus (*Citrus* spp.) in California and cassava (*Manihot esculenta*) in Africa [44], that protect urban *Eucalyptus* trees in California [45], and that control other non-native species that are invading native ecosystems [46]. Finally, regulatory services that benefit native species and ecosystems are common. This includes creating habitat for rare and endangered species, for example, habitat provided by *Eucalyptus* trees for monarch butterflies (*Danaus plexippus*) in California [47], the dispersal of propagules provided by non-native taxa, particularly in places like New Zealand where many native dispersers have gone extinct [48], pollination of native plants in South America [49], and even contributions towards the regulation of climate through enhanced carbon sequestration, for example, in the Mediterranean Sea [50]. Ultimately, these regulatory services associated with non-native species occur commonly and they often provide economic benefits (Box 1).

Intrinsic value

Intrinsic value in the context of conservation is inherent value, independent of relational or instrumental value, and is commonly ascribed to animal rights/welfare, ecological and evolutionary process, and species diversity [22]. These bio- or eco-centric values are commonly held by the general public. For instance, significant portions of the general public are opposed to efforts to eradicate non-native species because of animal rights and welfare concerns [51]. A survey in Europe found that 'nativeness' matters very little to people, relative to other considerations like species attractiveness [52], suggesting that the non-native status of a species does not negate its intrinsic value. Indeed, intrinsic value is commonly ascribed by the public to species, like wild (non-native) horses (*Equus ferus*) [53]. A similar trend is observed among scientists. For example, a recent survey revealed that over half (55%) of sampled conservation scientists believe that all species contribute to 'biodiversity' (including invasive species) and 87% believe that at least some non-native species contribute to the concept of biodiversity [54].

Non-native species also contribute to ecological processes wherever they occur, through pairwise and diffuse species interactions, as competitors, predators, and a source of resources [9,55]. Likewise, they contribute to evolutionary processes, ranging from local adaptation to speciation [56]. Indeed, in some regions, such as the UK, it is likely that more new plant species have evolved as a consequence of non-native species than have been lost as a consequence of their introductions [57]. The general outcome of non-native species is large increases in regional biodiversity: there are many more species now found in almost every region of the world than there were historically [14]. Non-native species can also provide a form of insurance against global species loss, as many non-native species at risk of extinction in their native range are often likely to persist where they have been introduced [58].

Concluding remarks and future considerations

Non-native species provide a wide variety of relational, instrumental, and intrinsic values for people and nature. We find the positive value of non-native species to be commonplace. Ultimately, any measure of value, whether positive or negative, will vary through space and time as a function of socio-ecological contexts, people's interests, and their worldviews [10,11] (Box 2). Collectively the representative examples we describe reveal a context for non-native species that is much more nuanced than the archetypical portrayal of them as being harmful and detrimental to human society.

The fields of conservation biology and invasion biology appear to be at a potential inflection point. On the one hand, these fields have been slow to acknowledge alternative normative views regarding non-native species (Box 2), and studies that purposely tally only negative components of non-native species (e.g., [5]) continue to be published along with misguided recommendations that they should serve as a basis for policy. Likewise, some invasion biologists have mistakenly identified some alternative normative views as forms of denialism [59]. On the other hand, once rare acknowledgments about the benefits some non-natives provide [6,7] have now been published in globally leading journals [8,9] and have culminated in the past few years in robust studies that explicitly compare both benefits and costs of non-native species [10–12]. We believe that the framework we provide here (considering the diversity of relational, instrumental, and intrinsic values) can help to advance this transition, so that the field is better positioned to initiate studies, generate results, and interpret findings in ways that best inform policy and public understanding.

To foster this transition, we suggest three research approaches to improve our understanding of non-native species and to help inform future policy decisions. First, future research that aims to examine how non-native species cause and facilitate changes in ecological systems should strive to differentiate between documented changes and valuations of those changes (whether positive or negative). This differentiation is particularly important when valuations are dependent strongly on normative perspectives, such as the nativist perspective that any change to an ecological system caused by a non-native species is necessarily viewed as harmful. Second, work that does consider valuations should aim to do so broadly, considering both negative and positive outcomes and, when possible, considering multiple types of values (e.g., instrumental, relational, and intrinsic). When a broad consideration of values is not practical then we should be explicit about the type or types of values being considered and the normative lens being applied. Third, because so little work to date has explicitly considered positive impacts of non-native species, there is a need for research to fill this gap through explicit consideration of these benefits. Such work could then be paired with existing tallies that have focused on negative impacts. This would allow for a wide range of important questions to be considered (see Outstanding questions). Asking and answering such questions in a more value-explicit way can help to clarify

Outstanding questions

Are positive effects of non-native species more likely to occur or to be of larger magnitude, on average, than negative effects?

Do positive or negative effects of non-native species vary with ecological or biogeographical settings?

Do positive or negative effects of non-native species depend on the type of value (relational, instrumental, and intrinsic) being considered?

Do the economic benefits exceed the economic costs of non-native species and how does this vary with ecological, biogeographical, or socio-economic context?

Does the relative frequency and magnitude of benefits and costs of non-native species vary with time since introduction, such that long-term outcomes differ from those manifested at shorter time scales?

the net impacts of non-native species, including how those effects vary in different contexts, and finally provide the type of information that is needed to make informed policy decisions.

Declaration of interests

No interests are declared.

References

1. Ewel, J.J. *et al.* (1999) Deliberate introductions of species: research needs: benefits can be reached, but risks are high. *BioScience* 49, 619–630
2. Coates, P. (2007) American Perspectives of Immigrant and Invasive Species. Strangers on the Land. University of California Press
3. Elton, C. (1958) The Ecology of Invasions by Animals and Plants. Methuen
4. Pysek, P. *et al.* (2020) Scientists' warning on invasive alien species. *Biol. Rev.* 95, 1511–1534
5. Diagne, C. *et al.* (2021) High and rising economic costs of biological invasions worldwide. *Nature* 592, 571–576
6. Westman, W.E. (1990) Park management of exotic plant species: problems and issues. *Conserv. Biol.* 4, 251–260
7. D'Antonio, C. and Meyerson, L.A. (2002) Exotic plant species as problems and solutions in ecological restoration: a synthesis. *Restor. Ecol.* 10, 703–713
8. Davis, M.A. *et al.* (2011) Don't judge species on their origins. *Nature* 474, 153–154
9. Schlaepfer, M.A. *et al.* (2011) The potential conservation value of non-native species. *Conserv. Biol.* 25, 428–437
10. Shackleton, S.E. and Shackleton, R.T. (2018) Local knowledge regarding ecosystem services and disservices from invasive alien plants in the arid Kalahari, South Africa. *J. Arid Environ.* 159, 22–33
11. Kelsch, A. *et al.* (2020) Invasive alien species and local communities in socio-ecological production landscapes and seascapes: a systematic review and analysis. *Environ Sci Policy* 112, 275–281
12. Kleitou, P. *et al.* (2021) Conflicting interests and growing importance of non-indigenous species in commercial and recreational fisheries of the Mediterranean Sea. *Fish. Manag. Ecol.* 29, 169–182
13. Clavero, M. and Garcia-Berthou, E. (2005) Invasive species are a leading cause of animal extinctions. *Trends Ecol. Evol.* 20, 110
14. Sax, D.F. and Gaines, S.D. (2003) Species diversity: from global decreases to local increases. *Trends Ecol. Evol.* 18, 561–566
15. Higgins, S.N. and Vander Zanden, M.J. (2010) What a difference a species makes: a meta-analysis of dreissenid mussel impacts on freshwater ecosystems. *Ecol. Monogr.* 80, 179–196
16. Charbonneau, B.R. *et al.* (2017) A species effect on storm erosion: invasive sedge stabilized dunes more than native grass during Hurricane Sandy. *J. Appl. Ecol.* 54, 1385–1394
17. Anagnostakis, S.L. (1987) Chestnut blight: the classical problem of an introduced pathogen. *Mycologia* 79, 23–37
18. Carey, M.P. *et al.* (2011) Smallmouth bass in the Pacific Northwest: a threat to native species; a benefit for anglers. *Rev. Fish. Sci.* 19, 305–315
19. Vimercati, G. *et al.* (2020) The importance of assessing positive and beneficial impacts of alien species. *NeoBiota* 62, 525–545
20. Katsanevakis, S. *et al.* (2014) Impacts of invasive alien marine species on ecosystem services and biodiversity: a pan-European review. *Aquat. Invasions* 9, 391–423
21. Goodenough, A.E. (2010) Are the ecological impacts of alien species misrepresented? A review of the "native good, alien bad" philosophy. *Community Ecol.* 11, 13–21
22. Pascual, U. *et al.* (2017) Valuing nature's contributions to people: the IPBES approach. *Curr. Opin. Environ. Sustain.* 26-27, 7–16
23. Boltovskoy, D. *et al.* (2022) Misleading estimates of economic impacts of biological invasions: including the costs but not the benefits. *Ambio* 51, 1786–1799
24. Chan, K.M.A. *et al.* (2016) Why protect nature? Rethinking values and the environment. *Proc. Natl. Acad. Sci. U. S. A.* 113, 1462–1465
25. Fortwangler, C. (2009) A place for the donkey: natives and aliens in the US Virgin Islands. *Landsc. Res.* 34, 205–222
26. Pfeiffer, J.M. and Voeks, R.A. (2008) Biological invasions and biocultural diversity: linking ecological and cultural systems. *Environ. Conserv.* 35, 281–293
27. Philips, J. (2021) The waterfinders: a cultural history of the Australian dingo. *Aust. Zool.* 41, 593–607
28. Pangua-Adam, M. *et al.* (2022) The role of the introduced rusa deer *Cervus timorensis* for wildlife hunting in West Papua, Indonesia. *Ecol. Solut. Evid.* 3, e12118
29. Schlaepfer, M.A. (2018) Do non-native species contribute to biodiversity? *PLoS Biol.* 16, e2005568
30. McManus, A. *et al.* (2011) *Identifying the Health and Well-Being Benefits of Recreational Fishing*. Report No. 2011/217, Curtin University of Technology, Centre of Excellence for Science, Seafood & Health
31. Arnett, E.B. and Southwick, R. (2015) Economic and social benefits of hunting in North America. *Int. J. Environ. Stud.* 72, 734–745
32. Johnston, R.F. and Garrett, K.L. (1994) Population trends of introduced birds in western North America. *Stud. Avian Biol.* 15, 221–231
33. Knight, C. (2019) A potted history of freshwater management in New Zealand. *Policy Q.* 15, 3–7
34. Hickley, P. *et al.* (2008) Economic gain versus ecological damage from introduced non-native freshwater fish: case studies from Kenya. *Open Fish Sci. J.* 1, 36–46
35. Jori, F. *et al.* (2013) An assessment of zoonotic and production limiting pathogens in rusa deer (*Cervus timorensis rusa*) from Mauritius. *Transbound. Emerg. Dis.* 61, 31–42
36. Zhou, M. *et al.* (2021) Enrichment of trace elements in red swamp crayfish: influences of region and production method, and human health risk assessment. *Aquaculture* 535, 736366
37. Parsons, J.J. (1972) Spread of African pasture grasses to the American tropics. *J. Range Manag.* 25, 12–17
38. dos Santos, L.L. *et al.* (2014) The cultural value of invasive species: a case study from semi-arid northeastern Brazil. *Econ. Bot.* 68, 283–300
39. Mehari, Z.H. (2015) The invasion of *Prosopis juliflora* and Afar pastoral livelihoods in the Middle Awash area of Ethiopia. *Ecol. Process.* 4, 13
40. Findlay, S. *et al.* (2003) Effects of *Phragmites australis* removal on marsh nutrient cycling. *Wetl. Ecol. Manag.* 11, 157–165
41. Ramus, A.P. *et al.* (2017) An invasive foundation species enhances multifunctionality in a coastal ecosystem. *Proc. Natl. Acad. Sci. U. S. A.* 114, 8580–8585
42. van Groenigen, J.W. *et al.* (2014) Earthworms increase plant production: a meta-analysis. *Sci. Rep.* 4, 6365
43. Stockdill, S.M.J. (1982) Effects of introduced earthworms on the productivity of New Zealand pastures. *Pedobiologia* 24, 29–35
44. Cullen, R. *et al.* (2008) Economics and adoption of conservation biological control. *Biol. Control* 45, 272–280
45. Paine, T.D. *et al.* (2015) Cost–benefit analysis for biological control programs that targeted insect pests of eucalypts in urban landscapes of California. *J. Econ. Entomol.* 108, 2497–2504
46. van Wilgen, B.W. *et al.* (2020) Quantifying the social and economic benefits of the biological control of invasive alien plants in natural ecosystems. *Curr. Opin. Insect Sci.* 38, 1–5
47. Longcore, T. (2020) Nearly all California monarch overwintering groves require non-native trees. *Calif. Fish Wildl.* 106, 220–225
48. Garcia, D. *et al.* (2014) Exotic birds increase generalization and compensate for native bird declines in plant-frugivore assemblages. *J. Anim. Ecol.* 83, 1441–1450
49. Medel, R. *et al.* (2018) The most effective pollinator principle applies to new invasive pollinators. *Biol. Lett.* 14, 20180132
50. Wesselmann, M. *et al.* (2021) Seagrass (*Halophilia stipulacea*) invasion enhances carbon sequestration in the Mediterranean Sea. *Glob. Chang. Biol.* 27, 2592–2607
51. Estévez, R.A. *et al.* (2014) Clarifying values, risk perceptions, and attitudes to resolve or avoid social conflicts in invasive species management. *Conserv. Biol.* 29, 19–30

52. Fischer, A. *et al.* (2011) Universal criteria for species conservation priorities? Findings from a survey of public views across Europe. *Biol. Conserv.* 144, 998–1007
53. Sharp, R.L. *et al.* (2011) Factors influencing public preferences for invasive alien species management. *Biol. Conserv.* 144, 2097–2104
54. Gbedomon, R.C. *et al.* (2020) Diverse views among scientists on non-native species. *NeoBiota* 54, 49–69
55. Twardochleb, L.A. and Olden, J.D. (2016) Non-native Chinese mystery snail (*Bellamya chinensis*) supports consumers in urban lake food webs. *Ecosphere* 7, e01293
56. Vellend, M. *et al.* (2007) Effects of exotic species on evolutionary diversification. *Trends Ecol. Evol.* 22, 481–488
57. Thomas, C.D. (2015) Rapid acceleration of plant speciation during the Anthropocene. *Trends Ecol. Evol.* 30, 448–455
58. Gibson, L. and Yong, D.L. (2015) Saving two birds with one stone: solving the quandary of introduced, threatened species. *Front. Ecol. Environ.* 15, 35–41
59. Fall, J.J. (2021) What is an invasive alien species? Discord, dissent, and denialism. In *Routledge Handbook of Biosecurity and Invasive Species* (Barker, K. and Francis, R.A., eds), pp. 40–54, Routledge
60. Ellender, B.R. *et al.* (2014) Managing conflicts arising from fisheries enhancements based on non-native fishes in southern *Africa*. *J. Fish Biol.* 85, 1890–1906
61. Seguy, L. and Long, J.M. (2021) Perceived ecological threats and economic benefits of non-native black bass in the United States. *Fisheries* 46, 56–65
62. Kerr, G.N. and Greer, G. (2004) New Zealand river management: economic values of Rangitata River fishery production. *Australas. J. Environ. Manage.* 11, 139–149
63. Pimentel, D. *et al.* (2000) Environmental and economic costs of nonindigenous species in the United States. *BioScience* 50, 53–65
64. Caltagrirone, L.E. and Doutt, R.L. (1989) The history of the vedalia beetle importation to California and its impact on the development of biological control. *Annu. Rev. Entomol.* 34, 1–16
65. Cassini, M.H. (2020) A review of the critics of invasion biology. *Biol. Rev.* 95, 1467–1478
66. Sagoff, M. (2005) Do non-native species threaten the natural environment? *J. Agric. Environ. Ethics* 18, 215–236
67. Russell, J.C. and Blackburn, T.M. (2017) The rise of invasive species denialism. *Trends Ecol. Evol.* 32, 3–6
68. Sala, O.E. *et al.* (2000) Biodiversity scenarios for the year 2100. *Science* 287, 1770–1774
69. Sheppard, A. and Glanznig, A. (2021) *Fighting Plagues and Predators: Australia's Path towards a Pest and Weed-Free Future*, CSIRO
70. Patten, M.A. and Erickson, R.A. (2001) Conservation value and rankings of exotic species. *Conserv. Biol.* 15, 817–818
71. Hobbs, R.J. *et al.* (2014) Managing the whole landscape: historical, hybrid and novel ecosystems. *Front. Ecol. Environ.* 12, 557–564