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Conflicting values: ecosystem services and invasive tree management

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Abstract Tree species have been planted widely beyond their native ranges to provide or enhance ecosystem services such as timber and fibre production, erosion control, and aesthetic or amenity benefits. At the same time, non-native tree species can have strongly negative impacts on ecosystem services when they naturalize and subsequently become invasive and disrupt or transform communities and ecosystems. The dichotomy between positive and negative effects on ecosystem services has led to significant conflicts over the removal of non-native invasive tree species worldwide. These conflicts are often viewed in only a local context but we suggest that a global synthesis sheds important light on the dimensions of the phenomenon. We collated examples of conflict surrounding the control or management of tree invasions where conflict has caused delay, increased cost, or cessation of projects aimed at invasive tree removal. We found that conflicts span a diverse range of taxa, systems and countries, and that most conflicts emerge

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around three areas: urban and near-urban trees; trees that provide direct economic benefits; and invasive trees that are used by native species for habitat or food. We suggest that such conflict should be seen as a normal occurrence in invasive tree removal. Assessing both positive and negative effects of invasive species on multiple ecosystem services may provide a useful framework for the resolution of conflicts.

Keywords Biological invasions carbon sequestration · Conflict resolution · Multidimensional evaluation · Non-native tree invasion · Tree invasions urban forests · Wildlife ecology

Introduction

Trees have enormous social, economic, landscape, and ecological importance, often regardless of whether a tree species is native or non-native. At the same time, many non-native tree species have naturalized and subsequently become invasive in their introduced range, and are now considered to be among the worst environmental threats facing many ecosystems around the world (Levine et al. 2003; Richardson and Rejmánek 2011). This can result in strongly dichotomous views of whether, when, and how non-native invasive tree species should be removed, and may ultimately lead to conflict over tree removal (Van Wilgen and Richardson 2014). Where such conflict results in increased costs, delayed removal, or cessation of removal efforts it becomes a direct concern to land managers. At the most extreme, tens of millions of dollars have been spent on biological control efforts that were eventually abandoned due to conflict over ~~other~~ ecosystem services (e.g. Davis et al. 2011).

Many of the world's societies attribute deep cultural significance to trees. Trees occur at the foundations of many cultures, including the Norse ash tree Yggdrasill upon which Odin committed self-sacrifice, the Biblical Tree of Life and Tree of Knowledge of Good and Evil, the Māori forest god Tāne who holds apart the sky father and the earth mother, the Bodhi tree under which Siddhartha Gautama meditated to become the Buddha, and the sacred groves of Shintoism, to name a few examples. Folklore, fairy tales, and legends emphasize trees and forests as defining elements, with trees taking both positive and negative roles. Trees also feature in modern children's literature, often with an explicitly environmental focus (e.g. Seuss 1972) but sometimes focusing on other ecosystem service provision (e.g. Silverstein 1964). This significance is partly driven by the vital provisioning services that trees provide, including timber for construction and furniture, pulp for paper manufacture, wood-based fuel, and tree fruit crops (Table 1). The relatively slow growth and longevity of trees have made tree conservation vital to long-term societal stability. Indeed, laws protecting trees date back to ancient times (e.g. Aristotle 350 BCE).

While many of the world's societies attribute deep cultural significance to trees, European colonial expansion reshaped attitudes towards trees globally and led to the distribution and introduction of many non-native trees worldwide. European colonialists brought trees indigenous to their native countries with them and also planted trees from Asia, Africa, and the Americas into novel locations for aesthetic and economic purposes (Pooley 2009). By the early nineteenth century European settlers and scientists began experimenting with a greater variety of genera and species of trees from around the world, with trees from Australia (especially *Eucalyptus* and *Acacia*) becoming extremely popular during the later nineteenth century (Bennett 2011). Whereas European settlers desired the aesthetics of alien trees (usually associated with the literature, art, and history of their native homes and trying to regain a sense of place), the rise of nationalism during the late nineteenth century encouraged residents to celebrate their own unique indigenous floras. By the mid-twentieth century, advocates for indigenous flora began to criticize non-native trees for threatening indigenous ecosystems and being ecologically foreign.

In addition to their cultural significance, trees provide food, shelter, material wealth, and ecological benefits to humans; these benefits have been termed "ecosystem services". The ecosystem services concept (Millennium Ecosystem Assessment 2005) recognizes the human-derived benefits of ecosystems within four categories of services: cultural, provisioning, supporting, and regulating (Table 1). On the one hand, the ecosystem services concept provides a mechanism for calculating economic costs of invasive

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Table 1 Ecosystem services, as defined by the Millennium Ecosystem Assessment (2005), and examples of their provision by invasive trees

Category	Example service	Major invasive tree genera commonly providing this service[a]
Cultural	Shade	*Acacia*, *Cinnamomum, Eucalyptus, Jacaranda, Pinus, Tamarix*
	Visual amenity/ornamental	*Acacia*, *Cinnamomum, Jacaranda, Larix, Pinus, Pseudotsuga, Rhamnus, Spathodea, Tamarix*
	Romantic trysts, privacy	*Eucalyptus, Pinus, Rhamnus, Salix*
Provisioning	Honey production	*Eucalyptus, Melaleuca*, *Robinia*
	Timber, building materials, poles, posts, pulp, crafts	*Acacia*, *Cinnamomum, Eucalyptus, Larix*, *Pinus, Pseudotsuga*, *Prosopis*, *Robinia, Tamarix*
	Tannins and other chemicals	*Acacia, Rhamnus*
	Firewood and charcoal	*Acacia, Eucalyptus, Pinus, Tamarix*
	Medicinal	*Acacia, Cinnamomum, Prosopis, Spathodea*
	Nut and fruit crops	*Psidium, Morus*
	Christmas trees	*Pinus, Pseudotsuga*
Supporting	Biodiversity (habitat and food provision for wildlife, protection from predators)	*Casuarina, Pinus, Tamarix*
	Nitrogen fixation (including improved fallow)	*Acacia, Casuarina, Falcataria*
	Fodder, shade for livestock	*Acacia, Prosopis*
Regulating	Carbon sequestration	*Acacia, Casuarina, Eucalyptus, Falcataria, Pinus, Pseudotsuga*
	Erosion control, including windbreaks	*Alnus, Acacia*, *Cinnamomum, Eucalyptus*, *Pinus*, *Rhamnus, Salix, Tamarix*
	Land reclamation	*Robinia, Tamarix*

[a] Citations: *Acacia* (de Wit et al. 2001), *Casuarina* (Thaman et al. 2000), *Eucalyptus* (Rejmánek and Richardson 2011), *Falcataria* (Mascaro et al. 2012), *Pinus* (Dickie et al. 2011), *Prosopis* (Wise et al. 2012), *Rhamnus* (Zouhar 2011). *Robinia* (Sakio 2009), *Spathodea* (Auld and Nagatalevu-Seniloi 2003), *Tamarix* (Smith 1941; Sher and Quigley 2013)

trees that can be used to justify removal and control efforts (van Wilgen et al. 2008). On the other hand, the ecosystem services concept provides a way to recognize positive effects of invasive non-native trees on provision of other ecosystem services, including economic, recreational, aesthetic, carbon sequestration and provisioning values (Dickie et al. 2011). Conflict can be interpreted as a failure to account for, assess, and balance trade-offs among these ecosystem services or, at times, a failure to agree on the relative value of particular services.

Methods

To better understand the causes and consequences of conflicts arising from invasive trees and ecosystem services, we review and summarize case studies from multiple countries (Table 2). We initially identified conflicts through round-table discussion and e-mail communication including participants from Argentina, Australia, Brazil, the Czech Republic, Canada, Chile, China, France, Japan, New Zealand, South Africa, and the United States of America. The list of potential conflicts was further augmented by searching both the scientific literature and the internet using adaptive heuristic search strategies to overcome the lack of consistent terminology across different types of conflicts.

Our analysis was based on the perspective of land-managers tasked with invasive alien tree removal. Land managers would almost certainly view conflict as negative where it resulted in the delay, cessation, or increased cost of invasive alien tree removal. This is both because dealing with conflict diverts time and resources away from the task at hand, and because it creates a negative perception of alien tree control operations. A land manager's viewpoint would be based on the assumption that alien tree removal is justified by the benefits of such removal, including the

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Table 2 Examples where invasive tree removal has been delayed, stopped, or increased in cost due to conflict over ecosystem services provided by trees

Control effort	Conflict	Outcome	Citations
Urban and near-urban trees			
Chicago, USA. Removal of non-native trees and shrubs (e.g. *Rhamnus*) from 80,000 ha of conservation land in order to restore native tall-grass prairie and *Quercus* savanna	Known as the "Chicago controversy": dramatic loss of woodland led to concerns over wildlife habitat, aesthetics, loss of privacy screening	Removal of invasive trees and shrubs slowed but not stopped. Widely studied and reported as a canonical example of environmental conflict	Alario and Brün 2001; Ross 1997
San Francisco, USA. Removal of over 18,000 trees, mostly *Eucalyptus,* from urban parks and forest areas	Several issues raised by opponents, but probably most critical an aesthetic concern over the loss of forested space in an urban environment	On-going conflict. Project mired in controversy, resulting in significant delay	Coates 2006; Sward 2012
Cape Town, South Africa. Removal of *Pinus, Eucalyptus, Acacia,* and *Leptospermum* from 265 km^2 World Heritage Site forest surrounded by urban area	Concerns over a number of issues, of which the following are supported: aesthetic value, recreational value, carbon sequestration, economic value (timber and honey production)	Concerns evaluated (van Wilgen 2012); non-supported concerns rebutted, trade-offs in supported concerns acknowledged. Some plantations of *Eucalyptus* retained to maintain aesthetic, recreational, and honey production values; partially on the basis that *Eucalyptus* is less invasive than *Pinus*. Concerns continue to be raised periodically	van Wilgen (2012)
Bellingen, Australia. Removal of four individual *Cinnamomum camphora* 90-year-old trees from downtown area	Trees considered to be heritage trees, part of character of town, and important shade source in centre of town	One tree removed, but ongoing controversy over the more than a million additional *Cinnamomum camphora* in valley	Macleay (2011)
Pretoria, "Jacaranda City", South Africa. Removal of planted ornamental *Jacaranda mimosifolia* to remove seed source driving invasion of savanna areas. Banning sales of this popular species in nurseries	*Jacaranda* is an iconic tree, symbol of the capital city of South Africa. Huge public resistance to removal and to regulations preventing replanting	Gradual phasing out, by preventing further planting or sale of seeds or plants. Seed source likely to remain for many decades, even centuries	Kasrils (2001)
Fiji. Control of *Spathodea campanulata* in rural areas being countered by continued planting in urban areas	*Spathodea* invades during agricultural fallow, very difficult to remove once established. Remains widely planted in urban areas for aesthetic values and in rural areas as living fence posts	Calls for programmes to increase awareness of weed problem before developing biological control, as well as to reduce planting. Species still promoted as an agroforestry tree	Auld and Nagatalevu-Seniloi (2003)
Direct economic benefits, including carbon sequestration			
South Africa. Planned biological control of invasive *Pinus* species by introducing cone-feeding weevil	Concern over adult weevil feeding on leader shoots allowing *Fusarium* fungal infection, with possible risk to commercial *Pinus* production	Biological control programme discontinued	Hoffmann et al. (2011)

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Table 2 continued

Control effort	Conflict	Outcome	Citations
South Africa. Removal of multiple species of invasive *Acacia*	Growing *Acacia* is important economic industry for production of tannins and timber, often grown by smallholders. Introduction of biological control for invasive exotic *Acacia* species in South Africa was prevented for decades due to desires to protect the interests of wattle growers	Removal efforts costing hundreds of millions of Rands. Eventual and grudging acceptance of biological control to reduce seed output. Use of lethal biological control remains blocked	Stubbings 1977; Van Wilgen et al. 2011; Impson et al. 2009
South Africa. Control of exotic *Prosopis* trees in South Africa	*Prosopis* is a valuable fodder tree, but it impacts negatively on groundwater and grazing resources. Biological control on seeds alone has been deployed but is ineffective. More lethal options are needed to make progress, but concern over the loss of benefits has prevented this to date	Aid agencies in many countries continue to promote these plants despite evidence of harm. Simultaneously, hundreds of millions of Rands have been spent on control. Spread continues at exponential rates. As with *Acacia*, the use of lethal biological control remains blocked due to economic utility of species	Wise et al. (2012)
Australia. *Salix* spp. eradication programmes alongside rivers and streams in the late 1980s. In 1999 *Salix* spp. were listed as 20 weeds of national significance (Willows Management Guide). River catchment authorities and councils in Tasmania, New South Wales, Victoria, Queensland, and Western Australia have pursued localized eradication efforts	*Salix* spp. are seen as important soil stabilizers. In northern New South Wales, where there is dieback of *Salix* spp., some advocate maintaining them. In the Upper Murrumbidgee River many see *Salix* spp. as part of the 'cultural landscape'. Farmers and some river hydrologists suggest eradication programmes may have had a tendency to 'over-shoot' by becoming an end (i.e. an anti-exotic species programme) rather than a means to better river management	Conflict has stopped the development of a national biological control programme since 2005. State and catchment programmes to remove *Salix* spp. still continue, but there is continued resistance by farmers and some scientists against the removal of all *Salix* spp. along rivers and streams. There is still no Commonwealth-approved biological control programme	Adair and Keel 2010; Rutherfurd 2010
Japan. Planned removal of *Robinia pseudoacacia* from riverbeds	*Robinia* very highly valued for production of honey	*R. pseudoacacia* presently being considered for inclusion in the list of the Regulated Living Organisms under the Invasive Alien Species Act. Bee keepers have been sending petitions to the Ministry of the Environment and the Ministry of Agriculture, Forestry and Fisheries to request that the government not add *R. pseudoacacia* to the list of the Regulated Living Organisms	Sakio (2009)
France. Listing of *Robinia pseudoacacia* as among "100 of the worst" invasive trees in Europe, due to formation of dense monospecific thickets, modifying soil properties and local biodiversity, and replacing native trees in riparian forest (*Salix alba*, *Populus nigra*, *Fraxinus excelsior*, *Alnus glandulosa*)	French government is actively promoting planting of *Robinia* to increase plant diversity in French South-West Maritime pine forests, including government provided financial subsidies	Simultaneous listing as invasive while promoting for planting continues, with the French government on both sides	Basnou (2006)

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Table 2 continued

Control effort	Conflict	Outcome	Citations
Otago, New Zealand. On-going efforts by volunteers to remove wilding conifers (*Pinus* and *Pseudotsuga*) from conservation grasslands	Government-funded planting of *Pseudotsuga* for carbon credits in land adjacent to conservation grassland	On-going controversy with threats of vigilante removal of planted trees	Fox 2012; Burrows et al. 2012
Support of wildlife (native and non-native)			
Western USA (13 states), release of biological control agent to control tamarisk	Tamarisk found to provide habitat for endangered native bird, the southwestern willow flycatcher.	Release of biological control agent halted after five years of investment by USDA. Control investment reported as $80 million USD over a 5-year period.	Davis et al. 2011; CBSNews 2010; Sher and Quigley 2013
Perth, Australia. Planned removal of 23,000 ha planted *Pinus* in the Gnangara Sustainability Strategy Area, partially to conserve water resources	*Pinus* found to be major food resource as well as habitat for endangered Carnaby's black-cockatoo	Importance of retaining some *Pinus* now recognized. Greater threat to black-cockatoo may come from urban development	Finn et al. (2009)
Western Cape, South Africa. Removal of invasive *Eucalyptus* trees from riparian zones to conserve water resources	Riparian *Eucalyptus* species provide the only viable nesting sites for the iconic African fish eagle	Ongoing concern about fish eagles. Debate places conservationists in conflict with conservationists	Welz and Jenkins (2005)

These are divided into three major categories: Urban and near-urban trees, species having direct economic benefits, and species providing habitat

protection of ecosystem services and native biodiversity. We recognise that conflict can highlight opposing societal viewpoints, and that this could lead to trade-offs that could in turn produce an improved (or more acceptable, and therefore more sustainable) outcome. Our goal was therefore not to depict conflict as purely negative, but rather to document the types of issues that lead to conflict, and to suggest ways to deal with them.

Our analysis of examples was non-quantitative and intended to collate and integrate examples and propose emergent patterns. Conflicts have previously generally been considered as isolated incidents and there has been little prior effort to integrate and find similarities across conflicts (although there is generally increasing appreciation that solutions to problems associated with biological invasions demand elucidation of the complex human dimensions involved; e.g. Kull et al. 2011). Some examples of conflict have been well documented in the scientific literature, notably conflicts over the removal of invasive trees from urban forests in Chicago, USA, and more recently Cape Town, South Africa (van Wilgen 2012) and conflict over *Tamarix* (Sher and Quigley 2013). For other examples this represents the first documentation in the scientific literature, as many conflicts are documented only in the wider media.

Results and discussion

Although details vary, we found informative examples of conflict over invasive tree removal across North America, Australasia, Africa, Asia, and Europe. Most documented conflicts were in developed rather than developing countries. Economic development tends to be correlated with increased rates of biological invasion (Nuñez and Pauchard 2010). Developed countries may also be more likely to have sufficient ecological awareness to result in invasive tree removal, individuals sufficiently wealthy to have time and resources to invest, and sufficient democracy to permit public discourse and dissent. We found no clear cases of conflict over invasive tree removal in South America, despite searching in both English and Spanish. This may reflect the relatively early stage of South American tree invasions relative to other countries (Richardson et al. 2008; Simberloff et al.

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2010) or social and economic factors limiting public dissent and discourse. There is an emerging literature on conflict over planted non-native trees in South America (e.g. Vihervaara et al. 2012; Paruelo 2012), but invasive trees have not entered that debate.

Conflict appears to be most common where trees occur in or near urban areas and provide aesthetic and recreational values (summarized in Table 2). Two other major types of conflict include where there are direct financial benefits derived from invasive trees, or where invasive trees provide food, habitat or predator protection for native wildlife. We discuss each of these broad categories of conflict in turn. Although our categorization necessarily simplifies complexity, it serves to highlight basic differences in the origin and, potentially, resolution of conflict.

Urban and near-urban trees

The best documented examples of conflict over tree removal have occurred where tree removal is in or near major urban areas. Examples of this include Chicago and San Francisco, USA, and Cape Town, South Africa (Table 2). Urban areas are frequently associated with large numbers of non-native plantings of a diverse range of species that, along with frequent disturbances, create an ideal environment for invasion (Moles et al. 2012). Issues are probably most obvious in cities with a long and sharp urban/wildland interface, as epitomized by Cape Town (Alston and Richardson 2006). Planted trees in urban areas are potential seed sources for invasion. Urban areas also tend to have educated, environmentally conscious populations likely to support and volunteer for removal or restoration efforts. Balancing against these factors, urban areas also place a high value on the aesthetic and recreational opportunities provided by non-native invasive tree species through their provision of shade, and plantings for green spaces, street plantings or gardens around urban centres.

Conflict over urban and near-urban trees is frequently vitriolic, as seen in letters to editors, public protests, and websites and blogs. Trees are long-lived and landscape-transforming, becoming part of the identity and "sense of place" of an urban area. Indeed, a number of cities around the world have non-native trees as important symbols (e.g. *Jacaranda* in Pretoria, South Africa, "the Jacaranda city"; Pinamar Argentina, named after *Pinus*; Bormes-les-Mimosa in France, and *Pinus ponderosa* in Twizel, New Zealand, the "town of trees") and non-native trees can become significant in local culture (e.g. "Jacaranda Festivals" in Grafton, Australia; "*Eucalyptus* School" of art, based in California, USA; Nuñez and Simberloff 2005).

An easy recommendation to make in managing urban and near-urban invasions would be to implement education before tree removal. However, the concept of "education" implies that opponents of tree removal are inherently ignorant or unaware and discounts the importance of their views and values. Sceptics of environmental issues are frequently highly educated and scientifically literate, with conflict driven by fundamental values, not lack of knowledge (Kahan et al. 2012). Further, what one party in a conflict views as education can be viewed as propaganda by those with opposing priorities. Therefore, we suggest that bidirectional dialogue may be more successful than a unidirectional education program. In establishing dialogue, it is critical to recognize shared values, particularly given that conflict over invasive tree removal often involves parties with strong conservation and environmental ethics on both sides of the debate. The ecosystem services concept may be particularly helpful in highlighting shared values, by providing a framework for recognizing the multiple service impacts (positive and negative) of invasive trees.

In some cases, removal of urban trees because they are non-native may represent an "over-shoot" (sensu Rutherfurd 2010), where the removal of non-natives becomes an end unto itself. Urban areas have a high density of potential volunteers, and non-native tree removal may have educational and cultural value. Objective evaluation of the ecological services affected may not result in the removal of non-native trees being justified. Indeed, in some cases the non-native trees being removed are not necessarily highly invasive, and removal is more driven by a desire for native species rather than any real or perceived problems caused by the non-native species.

Particularly in the case of urban and near-urban trees, a remarkable amount of controversy can be created by a single individual through newspaper articles, lawsuits, or Internet blogs. For example, an individual in Hawai'i has raised legal challenges against the removal of invasive mangroves and published articles opposing removal of strawberry guava

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(*Psidium cattleianum*) from native forest (Singer 2011). A common pattern in this opposition is that multiple arguments are raised simultaneously (e.g. non-target effects of herbicides or biological control agents, claims of "environmental Nazism" and "xenophobia", concerns over scenic values, wildlife values, and a range of other ecosystem services) which can make constructive dialogue difficult. Given sufficient time and funds, a single individual can effectively stall a project through legal challenges (this creates an interesting asymmetry, as a single individual could not, in general, remove a widespread invasive tree). What starts as an individualistic crusade can also swell to become a much broader movement. From a conflict management point of view, there is probably little hope that constructive dialogue will stop a strident individualistic opposition once started. Whether early engagement increases the probability of defusing the conflict would be worth investigation. At the least, having well-constructed arguments that objectively consider and compare costs and benefits of invasive trees, and that test whether and how urban trees contribute to propagule pressure, is critical to countering the arguments put forth by individual advocates. Collecting such data in urban areas need not be unduly expensive, particularly if the urban population can be used to collect data (e.g. Aslan et al. 2012).

Direct economic benefits, including carbon sequestration

The second major area of conflict is where invasive trees provide a direct economic benefit, or where the removal results in a direct and unexpected economic cost. Many invasive trees were intentionally introduced to support economic development or for cost avoidance, e.g. by soil protection on slopes and along rivers. Indeed, many of the worst invasive trees were initially planted for erosion control (e.g. Procheş et al. 2011). In more recent times, tree planting has been viewed as an important strategy for increasing carbon sequestration. This becomes a direct economic concern in countries that have commercialized carbon credits under the Kyoto Protocol. In many cases the economic benefits of a tree species accrue to a private party, while the ecosystem services costs of invasion may fall to the public.

Economic concerns can also be an issue in biological control where an invasive tree is closely related to commercial species. This is particularly the case for species in the genus *Pinus*, many of which are among the most invasive of trees, but also underpin many timber industries. Similar concerns have blocked the use of lethal biological control for *Acacia* and *Prosopis* in South Africa. In the case of *Acacia* and *Prosopis*, it is possible to introduce biological control agents to reduce seed production and thus propagule pressure. However, the development of pine biological control was discontinued in South Africa because of concerns that introduced weevils might cause increased susceptibility of commercial tree species to fungal infection (Hoffmann et al. 2011). While many of the economic values of invasive trees reflect their original purpose of introduction, there can also be unpredicted values that emerge after a tree becomes invasive. Tassin et al. (2012) refer to this as "conversion", giving the example of invasive *Acacia* becoming incorporated into agroforestry fallows in Africa and India. Nonetheless, in some cases the use of invasive trees by local people can be reflective of the loss of alternatives due to the invasion itself (e.g. *Prosopis* in Kenya; Mandu et al. 2009).

We have included carbon sequestration within direct economic benefits, as the only cases we found where actual conflict ensued involved carbon credits with cash value. Non-native trees frequently have high-biomass accumulation and have been promoted for carbon sequestration. This occurs for two reasons. First, forestry species are selected for climate suitability, and in particular for those species considered for C sequestration schemes, for their rapid growth (Procheş et al. 2011). Second, one of the most common effects of plant invasions ~~more generally~~, ~~but also~~ including forestry species, is an increase in above-ground carbon storage in ecosystems (Cardinale et al. 2012). More generally, non-native trees can alter ecosystem processes differently from co-occurring native species, including those processes affecting C sequestration (Ehrenfeld 2003; Levine et al. 2003). Invasive non-native tree species have relatively fast growth and, concomitantly, rapid increases in biomass C stocks (Jackson et al. 2002; Liao et al. 2008); as a consequence, non-native tree species are often promoted as drivers of C sequestration (Peltzer et al. 2010). The conflict that arises is thus between benefits from carbon or timber and costs associated with subsequent invasions. Further, the benefits are usually to a company or individual landowner whereas

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the costs are to neighbouring lands and often borne by the public or government (Burrows et al. 2012).

A common aspect of conflict over direct economic benefits is that it can place different management agencies or funders in direct opposition to each other. In France, for example, some government agencies are actively promoting the planting of *Robinia* at the same time as other agencies are listing it as a highly invasive tree (Préfecture de la Région Aquitaine 2010; Başnou 2006). Low (2012a, b) describes another example of this phenomena where the World Agroforestry Centre (ICRAF) simultaneously promotes and cautions against planting of *Prosopis* in Africa (also see Kull and Tassin 2012). Regardless of views on non-native trees, having multiple government agencies working directly at cross-purposes appears to be an inefficient use of resources.

Comprehensive economic evaluation can be used to compare different options and achieve consensus (e.g. Wise et al. 2012). However, strict economic analysis is highly dependent on the choice of future discounting rates, including discounting the cost of perennial control of seedlings on adjacent lands, and on decisions about how and whether to quantify the economic costs of biodiversity impacts (Wise et al. 2012).

Support of native and non-native wildlife

The third major area of conflict is where invasive trees provide habitat or food for wildlife, particularly species with high charismatic value (e.g. birds and butterflies). For example, removal of invasive *Tamarix* in the south-western USA was halted because an endangered bird, the southwestern willow flycatcher, used the invasive trees for nesting (Schlaepfer et al. 2011). Similarly, there is significant concern that removal of *Pinus* plantations near Perth, Australia, will result in declines in Carnaby's black-cockatoos, which use *Pinus* seed as a major food source as well as nesting in plantations. In Davis, California, more than 40 % of butterflies rely heavily on non-native plants, including many woody species (Shapiro 2002). In another example, non-native trees (notably *Eucalyptus*) provide the only suitable nesting sites for iconic African fish eagles in parts of South Africa, and these trees are now being cleared as part of projects to control ~~of~~ non-native tree along rivers (Welz and Jenkins 2005), leading to conflict between conservationists.

Wildlife may be particularly dependent on invasive trees where native trees have been largely eliminated from the landscape or where the invasive species substantially increases resource levels (Vitule et al. 2012). In New Zealand, for example, an endangered endemic spider, the katipo (*Latrodectus* spp.), uses driftwood as an important habitat for nesting (Griffiths 2001). The near-complete removal of native woody plants from this region has resulted in driftwood being largely derived from invasive woody shrubs and trees (L. R. Dickie and I. A. Dickie, unpublished data). Similarly, the reliance of Davis, California, butterflies on non-native plants may be driven by the rarity of suitable native plants within the city (Shapiro 2002). More generally, this sort of positive interaction tends to favour relatively common, generalist wildlife species over rarer, specialist endemic species (Allen et al. 1997). Habitat and food use can also represent an ecological trap with, for example, birds nesting in invasive woody species sometimes having reduced nesting success (Schmidt and Whelan 1999; Rodewald et al. 2010).

Interactions among invasive species can also be important in the ecosystem services provided by invasive trees (Schlaepfer et al. 2011). For example, invasive trees and other woody plants may shelter native wildlife from the effects of non-native invasive predators (Chiba 2010). In New Zealand, it has been suggested that introduced goats induce a dense growth form of the invasive shrub *Ulex europaeus*, the net effect of which is to protect a highly endangered insect, the Mahoenui giant weta (*Deinacrida mahoenui*), from predators (Sherley and Hayes 1993). Similarly, in Mauritius, plantations of *Pinus* and *Cryptomeria japonica* provide critical protection of the endemic Mauritius fody (*Foudia rubra*) and pink pigeon (*Columba majeri*) from nest predation by introduced predators (black rats *Rattus rattus* and crab-eating macaques ~~(~~*Macaca fascicularis*) (Safford 1997).

Where invasive trees have become important habitat, food, shelter or protection for native wildlife, removal efforts may be indefinitely delayed (e.g. Chiba 2010). In these cases it may be possible to achieve removal only after consideration of the timing and order of management activities, including invasive tree removal, management of other invasive species and/or restoration of natives. This may involve habitat restoration before invasive removal is possible.

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Nonetheless, in some cases it may be difficult or impossible to restore native species due to other anthropogenic changes in site conditions (e.g. hydrology, soil fertility) or due to introduced herbivores that can have negative direct effects, legacy effects, or through interactions with other species (Schlaepfer et al. 2011).

Management of invasive tree interactions with wildlife may be an area where ecological theory has significant value. Ecologists are increasingly recognizing the outcomes of community assembly, including long-term effects on ecosystem services, can depend on the history or order of species arrival into that ecosystem (Fukami and Morin 2003; Körner et al. 2008). This historical contingency is known as "assembly history", including concepts such as priority effects and multiple stable states. In the case of removing invasive trees, we suggest that a corollary—"disassembly history"—may be relevant. What remains unclear is whether the drivers and consequences of assembly history are similar to community disassembly; no direct tests of this have been done, but theory suggests these processes are incongruent (Petchey et al. 2008; Saavedra et al. 2008). Ecosystem disassembly has been studied in the context of native species extinction, particularly of animals (Petchey et al. 2008), and in invasive species removal, but again largely from an animal perspective (Zavaleta et al. 2001). We suggest that further research on disassembly history could focus on competitive interactions between invasive trees and other plants, trophic interaction networks with herbivores, and mechanisms for maintaining wildlife supporting services. Attention should also be paid to the effects of rate of change, particularly in biological control. For example, Dudley and Deloach (2004) suggest that biological control of *Tamarix* will be sufficiently gradual to permit native trees to generate, minimizing negative effects on native birds.

In addition to providing a conceptual framework for understanding wildlife supporting functions, the concept of disassembly history may also be important in mitigating legacies of invasive trees. For example, removal of invasive trees often results in invasion by non-native grasses, which in many cases can be more problematic than the original weed (Richardson et al. 2000; Rutherfurd 2010; Dickie and Peltzer, unpublished data). At the same time, invasive trees can also serve to facilitate ecosystem restoration and regeneration of native vegetation (Ewel and Putz 2004; Fischer et al. 2009; Pérez et al. 2012; Becera and Montenegro 2013), suggesting that delayed or staggered removal could enhance long-term ecological outcomes (e.g. Ruwanza et al. 2013).

Conclusions and solutions

Academic debate about whether invasive species are "good" or "bad" has not increased the ability of land managers to effectively control invasive species (Davis et al. 2011; Kull and Tassin et al. 2012; Low 2012a, b). In part, this reflects a tendency to dichotomize what is inherently a gradient (Pyšek and Richardson 2010); and in part the difficulty of integrating costs and benefits that accrue to different sectors of society with different values. Conflict can result when both sides of the argument fail to account for all of the issues or to assess the trade-offs between them.

We have highlighted examples of conflict in individual countries from Africa, Asia, North America, New Zealand, Australia, and Europe. The combination of increasing plant invasions around the world and generally increased wealth and democracy is likely to make such conflicts more widespread in the future. We suggest that conflict should be seen as a normal occurrence in invasive species removal, and that this emerges from the ecosystem services provided by invasive trees, including their aesthetic and recreational benefits. Although there are many examples of conflicts being resolved over time, there remain problems of negative publicity, increased costs, and delays due to conflict for land managers. Avoiding conflict entirely may be impossible, but a careful evaluation of ecosystem service provision and degradation by invasive trees may allow conflict to be mitigated and managed in more efficient ways using multiple ecosystem services as a conceptual framework for debate and decisions.

We propose that relating changes caused by invasive alien trees to ecosystem services provides a useful way of advancing discussions, as it explicitly allows for multiple ecosystem-service effects of invasive trees to be evaluated. Furthermore, it serves as a tool to elucidate many of the issues involved. Such elucidation is increasingly needed for complex environmental issues (e.g. Richardson et al. 2009). Evaluating the ecosystem services provided by invasive

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species is not trivial (Simberloff et al. 2013) and evaluating trade-offs in ecosystem services is even more challenging. One approach would be to convert all services to a single metric (typically a monetary value) in economic models (e.g. van Wilgen et al. 1996). The economic approach has the advantage of providing a single value that is both easy to communicate and can be directly compared with the costs of control. At the same time, economic quantification is fraught with subjective value judgments, has no inherent method for incorporating uncertainty, and the outcome is highly dependent on the choice of a discounting rate for the future. An alternative approach is to explicitly maintain the multiple dimensions/values of ecosystem services, rather than conflating these to a single metric (Richardson et al. 2009). This approach has the advantage of more explicitly capturing uncertainty while recognizing trade-offs among different services. In a study of conflict resolution using the ecosystem services paradigm (albeit regarding floodplain restoration rather than invasive tree removal), it was suggested that the process of quantifying multiple dimensions and values through participatory approaches can be more important than the outcome itself (Sanon et al. 2012).

The three areas of conflict (urban trees, direct economic benefits, wildlife support) reflect three of the four categories of ecosystem services under the Millennium Ecosystem Assessment (2005). Conflict over urban trees is primarily around cultural ecosystem services, conflict over economic benefits is primarily around provisioning services, and conflict over wildlife primarily is around supporting services. Regulating services appear most important where there is an immediate economic impact (e.g. *Salix* and river bank erosion in Australia, *Pinus* and carbon credits in New Zealand), but do not appear to be as important a driver of conflict. This may reflect, in part, the relatively weak connection between plant species identity and the provision of regulating services (Mascaro et al. 2012). The character of conflict appears to vary depending on the types of ecosystem services involved. Because provisioning services are relatively fungible, conflicts over these services ~~are~~ can be addressed by economic analysis of cost benefit trade-offs. Difficulties in resolving these more economic conflicts will remain where benefits accrue to different parties than incur costs, or where temporal and spatial scales of costs and benefits differ (Rodríguez et al. 2006). Conflict over wildlife services, in contrast, has been largely addressed through quantitative ecological analysis. This is reflected in the types of literature that have developed around economic and wildlife support conflicts, which tends to be primarily academic.

Conflict over cultural values has been much more dominated by public discourse and fewer attempts at quantitative analysis. In part this reflects the difficulty in quantifying cultural services (Carpenter et al. 2009; Frame and O'Connor 2011). This should definitely not, however, be taken to mean that cultural values can be ignored. Indeed, the observations in Table 2 suggest that cultural values often lead to more intense conflicts over invasive tree removal than other ecosystem services. We believe there is a need for greater dialogue between researchers from the social sciences (e.g. Frame and O'Connor 2011), urban forestry (e.g. Kirkpatrick et al. 2012), ecology and economics to create interdisciplinary models for assessing cultural ecosystem services.

For proponents of removal, engaging in dialogue requires a willingness to understand multiple perspectives and values around ecosystem services and potentially to accept that some invasive trees will not be removed. Indeed, in some cases removal may simply be beyond practicality and the focus must shift to mitigating impacts. Conversely, opponents of invasive tree removal may need to recognize that the positive aspects of invasive trees for some ecosystem services have to be weighed against the costs for other ecosystem services (Dudley and DeLoach 2004; Richardson et al. 2009). Even where present benefits outweigh costs, models of future spread and impact may suggest removal while such removal is still feasible.

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