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SPECIAL ISSUE: HUMAN-MEDIATED INTRODUCTIONS OF AUSTRALIAN ACACIAS—A GLOBAL EXPERIMENT IN BIOGEOGRAPHY

Adoption, use and perception of Australian acacias around the world

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ABSTRACT

Aim To examine the different uses and perceptions of introduced Australian acacias (wattles; *Acacia* subgenus *Phyllodineae*) by rural households and communities.

Location Eighteen landscape-scale case studies around the world, in Vietnam, India, Réunion, Madagascar, South Africa, Congo, Niger, Ethiopia, Israel, France, Portugal, Brazil, Chile, Dominican Republic and Hawai'i.

Methods Qualitative comparison of case studies, based on questionnaire sent to network of acacia researchers. Information based on individual knowledge of local experts, published and unpublished sources.

Results We propose a conceptual model to explain current uses and perceptions of introduced acacias. It highlights historically and geographically contingent processes, including economic development, environmental discourses, political context, and local or regional needs. Four main groupings of case studies were united by similar patterns: (1) poor communities benefiting from targeted agroforestry projects; (2) places where residents, generally poor, take advantage of a valuable resource already present in their landscape via plantation and/or invasion; (3) regions of small and mid-scale tree farmers participating in the forestry industry; and (4) a number of high-income communities dealing with the legacies of former or niche use of introduced acacia in a context of increased concern over biodiversity and ecosystem services.

Main conclusions Economic conditions play a key role shaping acacia use. Poorer communities rely strongly on acacias (often in, or escaped from, formal plantations) for household needs and, sometimes, for income. Middle-income regions more typically host private farm investments in acacia woodlots for commercialization. Efforts at control of invasive acacias must take care to not adversely impact poor dependent communities.

Keywords
***Acacia*, biological invasions, economic development, introduced species, livelihoods, natural resource management, subsistence harvesting.**

INTRODUCTION

Introduced Australian acacias (*Acacia* subgenus *Phyllodineae*, Fabaceae; Miller *et al.*, 2011; Richardson *et al.*, 2011), besides being commercially important crops, play diverse roles in the lives and livelihoods of rural communities around the world (Fig. 1). Yet peoples' interactions with acacias are not uniform. In some places, like highland Madagascar, introduced acacias are universally accepted, widely utilized and even celebrated, despite displaying invasive behaviour. In others, like on the slopes of Réunion and Hawaiian islands, the plants presently play a minor (if any) economic role, are of little concern to the

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Figure 1 Facets of community uses of introduced Australian acacias in different parts of the world. Row 1: woodfuel and construction use; environmental education with orphans, in South Africa. Row 2: acacia businesses in France (cut flower) and Réunion (fuel for distillery); *Acacia mearnsii* on ranch in Maui. Row 3: woodfuel in Palni Hills, India; land rehabilitation in Tamil Nadu, India; agroforestry in Niger. Row 4: acacia seed *injera*, Ethiopia; catchment restoration, Ethiopia; acacia flowers for sale, Chile. Row 5: acacia fuel for industrial boiler, charcoal kiln and acacia-tanned leather, Madagascar. Row 6: acacia harvest, furniture and branding, Vietnam. Photo credits: M. Aitken (1a,b); MZ (1c); CAK (2a,b, 3a,b, 5a,b,c); Forest & Kim Starr (2c); TR (3c, 4a,b); AP (4c); SJM (6a,b,c).

public and are seen by many environmental managers as weeds. In yet other places, like South Africa, the situation might be described as a mix of the above examples with the addition of major industrial uses for pulp and tanbark (van Wilgen *et al.*, 2011). We seek to untangle these differences by asking three questions: What are the key values of introduced Australian acacias to rural households and communities around the world? Under what conditions do they gain these values? What factors best explain the differences observed between acacia values in different regions of the world? Answering these questions provides both empirical evidence and conceptual arguments to allow environmental managers a better understanding of the social context they encounter when managing introduced species.

The current values of introduced acacias in diverse rural communities around the world are complex outcomes of historically and geographically contingent processes that integrate plant ecology, economic development, political context and culture (Kull & Rangan, 2008; Carruthers *et al.*, 2011). Planted in different eras for diverse motivations linked to rural development and land restoration, they grow in landscapes that present a variety of environmental constraints and opportunities (Richardson *et al.*, 2011). Their use is shaped by land use traditions, historical and current economic opportunities, subsistence needs, or by structures of land (and tree) access. Together, these factors shape contemporary uses and perceptions of the trees (Fig. 2).

The adoption of plants into local livelihoods is as old as humankind itself. The adoption of plants introduced from elsewhere is nearly as old, although the increased volume, distance and speed of human movement have increased opportunities in recent centuries (Wilson *et al.*, 2009). The ways in which plants arrive and spread in new landscapes play a role in their later adoption by humans. Kull & Rangan (2008) distinguish three kinds of movement. 'Transfer' refers to the transoceanic movement of plants by scientists, traders or others. 'Diffusion' evokes local and regional plant movements by foresters, development agencies, commercial nurseries, farmers or gardeners. 'Dispersal' encompasses the process of plant spread by water, wind, insects, animals and so on. All kinds of movement are crucial to community adoption of plants, as they play important roles in the plant's distribution and in the knowledge, technology and ideas accompanying the

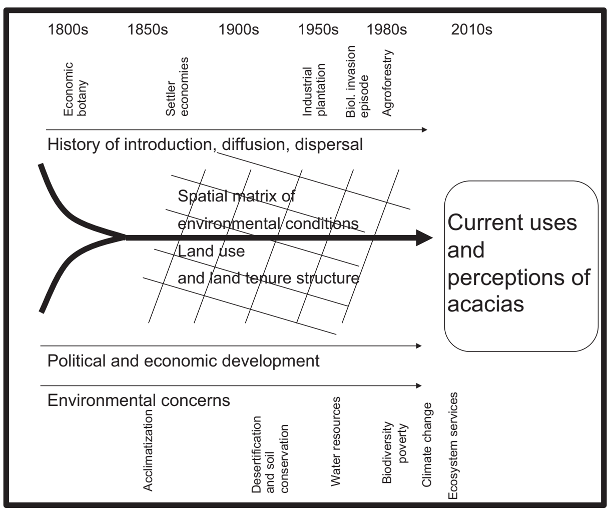

Figure 2 Key spatial and temporal processes shaping the values attached to introduced Australian acacias in different parts of the world.

plant. As Kull & Rangan (2008) specify, the transfer and diffusion of plants includes the accompanying bundles of knowledge, such as ideas on cultivation and use, links to marketing networks or even biocontrol agents, which can shape outcomes and uses in different regions.

Australian acacias have followed multiple pathways on their way into contact with rural households and communities. These include scientific forestry breeding and propagation processes (cf. Midgley *et al.*, 2011), as well as historical introductions for obsolete purposes, accidental introductions and self-propagation, community agroforestry programs and parallel adoption by individuals outside formal interventions, as we describe in this article.

Once present, why do rural communities adopt new plants? People use both indigenous and introduced plant species to meet their needs for energy, shelter, medicine, food, spirituality and culture, as well as trade in plant products to generate cash income (Cunningham, 2001). Traditionally, potentially useful species have been tried and tested to identify those with superior qualities, which may be further enhanced through selection and domestication. However, the widespread spontaneous use of introduced species, such as for medicinal purposes (Dold & Cocks, 2000; Sarma & Sarma, 2008), edible leaves and fruits (Shackleton *et al.*, 2007; Maundu *et al.*, 2009) or locally preferred woodfuels (Higgins *et al.*, 1997), suggests that such trial and error screening can be rapidly achieved, not just over generations as previously assumed. Once such uses become ingrained in how people make a living, in their culture, and in how they view themselves, one can consider a plant 'adopted' in a broader, sociocultural sense.

Drivers of the use and adoption of introduced species in preference to or alongside indigenous species have not been systematically examined. These are assumed to be related to situations where the local opportunity costs of not using the introduced species are too high, or where a new resource is not available locally (Shackleton *et al.*, 2007). Favourable opportunity costs may occur for example when (1) the introduced species boasts superior qualities, such as yield, growth rate, productivity, abundance, taste, wood quality, lack of thorns, etc. (Richardson, 1998; Richardson *et al.*, 2004), (2) it occurs abundantly and in closer proximity than indigenous species and so requires less labour to propagate or harvest, and (3) use may help control its spread and thus reduce its potential negative impacts. These economic arguments are adequate where there is a tangible product and can be used to estimate probabilities of adoption. However, ornamental, aesthetic or cultural uses do not fit such models and can only be explained by personal preferences, cultural traditions and popular perceptions. In such circumstances, a more nuanced and socially and historically explicit understanding is required (Kull & Rangan, 2008).

The adoption of new plants differs whether a plant has been diffused for a specific use or whether its presence in a community is indirectly because of a nearby plantation or the plant's own dispersal. In the latter case, whilst initially reliant on collections from spontaneous populations, many communities evolve a range of management interventions (e.g.

Colunga-Garciamarin & Zizumbo-Villarreal, 2004) to either improve specific traits (such as fruit size, taste and growth rate) or to secure more reliable and larger harvests. These range from management or protection of individual plants in the wild (such as clearing competing vegetation; protection from fire), through to planting around the homestead or fields, and ultimately domestication (Table 1).

The most common pathway for the adoption of introduced acacias has been recognition by rural communities of the utility of trees that have spread beyond an initial introduction for timber plantations, restoration or as shade/auxiliary trees in cash crop plantations (Rouget *et al.*, 2002; Kull *et al.*, 2007). A secondary one is where they have been actively promoted by outside agencies to rural communities for some developmental or utilitarian purpose, such as agroforestry (e.g. Nyadzi *et al.*, 2003), fuel and timber woodlots (Midgley *et al.*, 1996; Kabir & Webb, 2005), or food security (Rinaudo & Cunningham, 2008), often accompanied by transfers of knowledge in, for example, silviculture or charcoal production.

Building on the above, we hypothesize for our global review of acacia values that some of the key differences in terms of use, relative levels of reliance and perceptions of acacia will result from combinations of the following biophysical, social and what we call 'familiarity' factors:

Biophysical characteristics and environment

The species of acacia, the characteristics of the surrounding environment, and whether a tree grows and spreads on its own (i.e. invasiveness) will shape the human use value.

Social context

Poorer people will rely more on acacias for subsistence needs, whereas in richer economies tree use depends on specific commercial markets. The opportunities for such uses will be affected by the structure of land tenure (state-owned, community access and private farm) and by prevalent environmental discourses, policies and development levels (Nuñez & Pauchard, 2010) in a particular region.

Familiarity

Uses and perceptions of acacias will be shaped by the original purpose of introduction (and accompanying infrastructure, knowledge and skills transfer), whether introduction was direct to a community (i.e. through projects) or indirect (i.e. via adjacent plantations), the length of time a species has been present, its proximity to communities and its abundance.

METHODS

This global review seeks to understand the historical and geographical context (Fig. 2) of acacia uses and perceptions in specific locations around the world. The current outcome of these historical and geographical processes is expressed in the biophysical, social and familiarity factors listed above.

To empirically catalogue values of introduced acacias to rural households and communities around the world, and to facilitate a comparison of the enabling conditions in different places, we used a comparative case study approach. We sought case studies in places where introduced acacias have a known presence in the landscape, and where acacias have been used by local communities [defined as individuals, households, family businesses, collective groups and projects, and excluding large-scale (> 1000 ha) plantations for commercial purposes by private companies or state agencies]. The scale of the case studies was specified as subnational landscape units of reasonable comparability.

Table 1 A continuum of management systems of introduced Australian acacias by rural communities (adapted from Wiersum, 1997).

	System	Management
Increasing human intervention ↓	Wild populations (naturalized, perhaps invasive)	Uncontrolled collection from the wild Controlled collection from the wild Directed actions to stimulate growth or regeneration of wild occurring individuals or patches Wild land enrichment
	Maintained populations	Nurturing or planting of wildlings in human-dominated landscapes, homesteads or gardens (e.g. agroforests) Maintaining adults *in situ* when clearing lands for cultivation or occupation Protection of sites or individuals (for utilitarian or cultural reasons)
	Cultivated populations	Cultivation and regeneration of acacias as a secondary or supplementary crop in (or around) homesteads, gardens or fields Planting of acacias for cultural reasons, such as to mark burial sites, temple trees, grave sites, etc.
	Domesticated populations	Establishment of plantations in which the acacia is actively planted, tended and is the dominant crop Selection through time for desirable traits (e.g. taste, size, growth rate)
	[In some situations] Controlled populations	Containment or reduction of weedy acacias (Wilson *et al.*, 2011)

Questionnaires were sent via networks of acacia researchers to over three dozen targeted individuals beginning with attendees at the 2010 introduced acacia workshop in Stellenbosch and snowballing to others known to these respondents or in the literature, with a list of questions representing the social, biophysical and familiarity factors mentioned above and designed to elicit local details and facilitate comparison. From responses, 18 case studies were of sufficient detail to merit inclusion (Fig. 3). Key gaps in the sample include north and east Africa, peninsular and insular south-east Asia, and China. Content is based on personal experience of experts and cited sources. Case study information was compared using qualitative methods. Crosscutting themes and patterns of similarity and divergence were identified by comparing subsets of the sample sorted by different variables.

CASE STUDIES AND RESULTS

We summarize the findings of the research, case by case, loosely organized from east to west. For each case study, we briefly highlight key historical processes (cf. Fig. 2) and pertinent social, biophysical and/or familiarity factors. Table 2 presents additional comparative detail for each case, while Table 3 generalizes the impacts of various biophysical, social and familiarity variables across the case studies.

1. Designated forestry zones, Vietnam

Vietnam's government has embarked on an ambitious reforestation program over the past two decades to supply burgeoning demand for wood products, with high reliance on acacias (particularly *Acacia mangium* Willd. and *Acacia auriculiformis* A. Cunn. ex Benth.). Of the 580,000 ha of acacias planted on government-designated zones, over two-thirds are a locally developed hybrid. While most are managed as formal plantations, some acacias are also planted on farms, around homesteads, and along canals and roadsides. About half of the plantations are owned by small farmers (< 20 ha each) who gain access to lands through 1994 and 1999 laws granting privatized rights to formerly communal land. Acacia wood is sold domestically as well as exported, as timber (particularly for furniture), pulp and woodchips. These plantation activities provide significant income (Fisher & Gordon, 2007), yet are criticized for being forced on farmers in locations at great distance from markets, for displacing other locally important land uses, and for being a vehicle for enrichment of village elites at the expense of the poor (Sowerine, 2004). Acacias also serve as windbreaks, woodfuel and a form of saving (Midgley *et al.*, 1996).

2. Palni and Nilgiri Hills, southern India

The British introduced Australian acacias to south Indian hill stations in the 19th century for woodfuel and ornamental

Figure 3 Locations of case studies. Symbols reflect dominant types of acacias ('coastal wattles' include *Acacia cyclops*, *A. longifolia* and/or *A. saligna*; 'tropical wattles' include *A. mangium* and *A. auriculiformis*; 'dry zone wattles' include *A. colei* and others).

Table 2 Summary of case studies. Sources: authors plus references in text.

Name	Primary species	Key Dates (Introduction; Diffusion)	Scale of presence	Land use/tenure	Historical uses	Key current uses	Use or sale?	Management (terms from Table 1)	Framing of policy context	National economic development (GDP per cap PPP*)
Government-designated forestry zones, Vietnam	*Acacia auriculiformis, Acacia mangium*	I: 1960s D: 1990s-	*c.* 580,000 ha	50% small-scale (< 20 ha) farmers; rest larger plantations	n/a	Industrial wood (woodchips, pulp, furniture). In farms: windbreak, woodfuel	Majority commercialized – national/intl markets	Domesticated (formal plantations & farm trees)	Reforestation and industrial growth	Poor-mid (2787)
Nilgiri and Palni Hills, India	*Acacia mearnsii,*	I: 1880s D: 1950–1970	*c.* 350,000 ha	Large government plantations; some private woodlots or trees	Woodfuel, tannin	Woodfuel, tanbark, pulp, light construction	Commercialized – local markets	Domesticated & Wild (largely abandoned industrial plantations)	National self-sufficiency (historically), greenery (today)	Poor-mid (2946)
Réunion Island	*A. mearnsii*	I: 1870s D: 1950s	5% of island	Private farmland	Woodfuel for distilleries	Crop rotation with Pelargonium, woodfuel	Local use	Wild (spontaneous regrowth)		Rich (33058)
Central highlands, Madagascar	*Acacia dealbata*	I: 1898 D: 1910-present	*c.* 300,000 ha	Private woodlots, lineage-based farm and fallow lands, common lands	Reforestation, woodfuel	Woodfuel, charcoal, poles and construction, soil fertility, etc.	Local use, some commercialization urban market	Mostly Wild, occasional seeding	Barren landscape needs regreening	Very poor (1054)
Albert-Luthili, eastern Mpumalanga, SA	*A. mearnsii*	I: 1800s; D: 1900s	Roughly 5% of area	Communal lands incorporating para-statal plantations	Tanbark and pulp	Woodfuel/charcoal, poles, construction, etc.	Local use, some commercialization national market	Both Domesticated and Wild (plus invasive control)	Water scarcity, poverty, biodiversity	Mid (10116) (poorer zone)
AmaZizi & AmaGwane, Kwa-Zulu Natal, SA	*A. mearnsii*	I: 1800s D: mid-1900s	< 5% of area	Communal lands (mix of common and private)	Woodfuel, timber, protect native forest	Woodfuel/charcoal, poles, construction, etc.	Local use, some local commercialization	Both Domesticated and Wild (plus invasive control)	Ditto	Mid (10116) (poorer zone)
Private land areas, Western and Eastern Cape, SA	*A. longifolia, A. mearnsii, Acacia melanoxylon, Acacia saligna*	I: 1800s D: 1900s	Several 100,000 ha	Private lands, nature reserves, informal settlements	Woodfuel, timber, tannin	Woodfuel, poles, construction	Local use, some commercialization	Wild (plus inv. species control)	Ditto	Mid (10116) (wealthier zone)
Cape Flats, Western Cape, SA	*A. cyclops, A. saligna*	I: early 1800s, Est: by 1870	47,977 ha; 39% of area	Private farmland, public land	Sand stabilization, woodfuel	Woodfuel, charcoal, poles	Local use; commercialization to urban market	Wild (plus inv. species control)	Ditto	Mid (10116) (high disparity)

Table 2 (Continued).

Name	Primary species	Key Dates (Introduction; Diffusion)	Scale of presence	Land use/tenure	Historical uses	Key current uses	Use or sale?	Management (terms from Table 1)	Framing of policy context	National economic development (GDP per cap PPP*)
Bateke highlands, DR Congo	*A. auriculiformis*	I: 1970s D: 1987-	8000 ha plantation	Use rights to 25 ha plots given to families	Industrial plantation	Charcoal, fallow soil restoration	Commercialized – urban markets	Domesticated	Major urban charcoal need	Very poor (314)
Maradi region, Republic of Niger	*Acacia colei, A. elacantha, A. tumida, A. torulosa,*	I: 1970s- D: 1980s-	< 700 ha in formal fields; more outside	Customary tenure farmlands	Windbreaks, reforestation, woodfuel	Woodfuel, poles, tool handles, food, soil fertility, wind protection, etc.	Local use	Domesticated	Wood scarcity, famine	Very poor (683)
Tigray, Ethiopia	*A. saligna*	I & D: 1970s-	Scattered, around crop field edges	Smallholder farmers (but weak land rights)	Land rehabilitation	Fodder, woodfuel	Local use	Cultivated	Wood scarcity, famine	Very poor (869)
Mediterranean and desert regions of Israel	*A. saligna and several others*	I: 1920s-	Figures n/a; uniform stands	On state-owned lands	Land rehabilitation, soil stabilization, fodder	n/a	n/a	Wild		Rich (27905)
Côte d'Azur, France	*A. dealbata*	I: 1800s	Figures n/a; uniform stands	Residential, small private farms, state forest	Essential oil, cut flower, ornamental	Essential oil, cut flower, ornamental	Commercialized – international markets	Domesticated and Wild		Rich (33058)
Central coastal Portugal	*A. longifolia*	I: 1897–1940s	*c.* 2850 ha of 24,000 ha coastal strip	Mostly state lands	Afforestation, sand stabilization, rehabilitation, woodfuel, forest products,	Marginal use of woodfuel, ornamental	n/a	Wild	Afforestation & dune stabilization (historically); use restricted by law (today)	Rich (23254)
Rio Grande do Sul, Brazil	*A. mearnsii*	I: 1928 D: 1930s-	156,000 ha	Private farmland	Tanbark, pulp, woodfuel	Tanbark, charcoal, woodfuel, pulp, reforestation	Commercialized – national markets	Domesticated		Mid (10304)
Bio-Bio, Chile	*A. dealbata*	D: early 1900s	5–10% of land area	Private farmland	Erosion control	Woodfuel, charcoal, ornamental	Commercialized – urban markets	Wild		Mid (14436)

Table 2 (Continued).

Name	Primary species	Key Dates (Introduction; Diffusion)	Scale of presence	Land use/tenure	Historical uses	Key current uses	Use or sale?	Management (terms from Table 1)	Framing of policy context	National economic development (GDP per cap PPP*)
Dominican Republic	*A. mangium*	I&D: 1980s	Locally very common	Smallholder farmland	Social forestry project	Construction timber	Commercialized – national markets	Domesticated		Mid (8125)
Hawai'i	*A. mearnsii*, *A. melanoxylon*	D: 1910s–1960s	< 100 ha planted	Forest reserves and large private landowners	Watershed; wood products; woodfuel	n/a		Wild (control as inv. spp.)		Rich (46350)

*2008 GDP per capita calculated at purchasing power parity (current international $) from World Bank (data.worldbank.org, accessed 13 September 2010).

purposes; *Acacia melanoxylon* R.Br. is now widespread in gardens and homesteads. From the 1950s, Indian foresters planted *Acacia mearnsii* de Wild. on montane grassland to replace tannin imports, because of suspended trade relations with apartheid South Africa and a desire for national self-sufficiency in industrial raw materials. Plantations covered some 350,000 ha (Del Lungo *et al.*, 2006). With resumption of trade with South Africa, there has been a decline in commercial exploitation, and most plantations have become senescent. However, local households use the acacias in several ways and appreciate them for their perceived woodfuel, soil, and climate benefits (Rangan *et al.*, 2010). Some forest labourers harvest trees from auctioned state forest or private woodlots for a small regional market in tanbark and pulp. Hundreds of women from local villages and towns earn a daily income by selling one headload of acacia woodfuel, harvested with permission from the Forest Department from its plantations.

3. Leeward slopes of Réunion Island

Following initial interest in *A. mearnsii* for tanbark, planting of this tree increased in the mid-20th century to supply fuel for geranium distilleries (the island dominated global export at the time). A collapse of the geranium market in the mid-1960s led to the fallowing of many fields, which were invaded by *A. mearnsii*. Today, small-scale geranium production continues. Farmers continue to use this acacia for woodfuel, sometimes rotating geranium fields with acacia fallows. *Acacia mearnsii* extent, however, far exceeds its utility: it now covers about 5% of the island's land surface and is considered a problematic invader in relatively intact habitats (Tassin & Balent, 2004; Baret *et al.*, 2006).

4. Vakinankaratra, central highlands, Madagascar

Authorities widely distributed *Acacia dealbata* Link in this open, grassy landscape from the early 20th century through to the 1960s. Goals included 're-greening' a perceived degraded landscape, supplying fuel to villagers and the railway, and roadside shade. The species is now ubiquitous above 1200 m, affecting an estimated 300,000 ha in various densities (Kull *et al.*, 2008). The species makes a valuable contribution to rural subsistence livelihoods (Kull *et al.*, 2007; Tassin *et al.*, 2009). Villagers heavily exploit this plant from 'wild' stands, particularly as a source of domestic woodfuel. In higher altitude zones, where alternative incomes are fewer, villagers seed acacia woodlots for the purpose of charcoal production sold in cities. Acacias also provide fertility, through the use of leaves in compost or field rotations.

5. Albert Luthuli Municipality, Mpumalanga, South Africa

This former plantation area near the Swaziland border hosts fairly dense settlements of poor rural households. *Acacia mearnsii* has spread outside plantations, particularly along waterways, and is a critical resource for local communities.

Table 3 Influence of key variables on acacia values across case studies. Note that variables are highly inter-related and operate at multiple scales.

	Variable	Influence
Biophysical	Species identity	While certain species were introduced for specific industrial uses (*Acacia mearnsii* for tannin, *Acacia mangium*, etc. for pulp), communities make use of all acacias for subsistence needs and small-scale industry
	Environmental context (for acacias)	Acacias at limit of environmental range (frost, soil type, aridity, competition) are often still appreciated by communities (e.g. France, Niger)
	Environmental context (for humans)	Lack of alternative woody resources increases community needs and hence acacia adoption. In tree-rich areas, poor people rely less on acacias for subsistence but still utilize them commercially (e.g. Congo, Vietnam)
	Invasiveness	Strong influence on familiarity (see below) and on labour investment to plant or control the trees
Familiarity	Ubiquity	Where a plant is omnipresent and people have needs, uses will be found; otherwise, widespread use requires project intervention
	Proximity	Affects both familiarity and economics of use
	Length of presence	Not directly related to level of use (compare Vietnam and Brazil), but indirectly influences invasiveness and hence ubiquity (see above)
	Direct vs. indirect use	Some communities use acacias for the reasons they were introduced (both agroforestry and large-scale industrial); others opportunistically use plantation or invasive trees for other uses (typically subsistence and small-scale commercial)
	Management regime	Deliberate cultivation vs. the harvest of 'wild' populations implies large differences in resource outlays: people will utilize most easily accessible resource
	Knowledge transfer	Plays little role in acacia cultivation or basic uses (woodfuel, construction), but important for specialized uses (tannin or perfume extraction).
Social	Wealth and need	Acacias highly utilized by poor communities; subsistence uses disappear with economic development. Concern with invasives related to national wealth.
	Original purpose of diffusion	Where historical diffusion was linked to a specific industry (tanbark, pulp and industrial woodfuel), current use is shaped by the fortunes of that industry (compare South Africa, Vietnam and Brazil with India, Réunion and Hawai'i)
	Land and tree tenure	Commercial uses mostly rely on secure tenure arrangements; subsistence uses sometimes rely on fragile access arrangements to state (India), private (South Africa) or communal (Madagascar) land.
	Environmental paradigms and government politics	Different political priorities at different times afforded to economic development (e.g. Vietnam), reforestation (e.g. Madagascar), or water resources and poverty alleviation (e.g. South Africa) affect acacia expansion, perception and use

Box 1 South Africa's Australian acacias

South Africa was one of the earliest and most zealous recipients of Australian acacias. Numerous species were diffused for different reasons across its diverse ecological and social landscapes. Acacias were introduced to the Cape by the early 19th century for fuel, sand stabilization and ornamental purposes (Le Roux *et al.*, 2011). In the 20th century, government grants and free seeds promoted the planting of large-scale acacia woodlots, to make the tree-poor country self-sufficient in wood products, from mining timber to tanbark (Witt, 2005). At their peak in 1981, formal *Acacia mearnsii* plantations covered 146,000 ha, compared with 96,000 today. South Africa continues to be the world's primary tannin exporter (Griffin *et al.*, 2011), and given *A. mearnsii*'s other uses for wood chips and pulp, it has been called the most profitable forestry species in South Africa (but see De Wit *et al.*, 2001). Invasive stands of this acacia now occur in over 20% of quarter-degree cells of South Africa, Lesotho and Swaziland (Rouget *et al.*, 2004). Several acacias are now listed as 'major' (nine species) or 'emerging' (three species) invaders, affecting nearly all regions except for the arid north and humid tropical eastern lowlands (Nel *et al.*, 2004). These species are targeted for control by the post-Apartheid job-creating environmental management programme 'Working for Water' to enhance ecological integrity, water security and social development (Turpie *et al.*, 2008; van Wilgen *et al.*, 2011). As the case studies demonstrate, acacia woodfuel, charcoal, poles and planks are important resources for large numbers of poorer South Africans. On the other hand, Australian acacias have had negative effects on biodiversity and ecosystem services in many parts of South Africa (Richardson & van Wilgen, 2004; van Wilgen *et al.*, 2008; Gaertner *et al.*, 2009; Le Maitre *et al.*, 2011). Devising strategies to manage Australian acacias across their entire range in South Africa, acknowledging not only the commercial importance of some species, the usefulness of other species for rural communities, but also the harmful effects of invasive acacias in many parts of the region, is a major challenge (van Wilgen *et al.*, 2011).

All households use this acacia as cooking and heating fuel. It is used for construction, fencing, minor wood products and as medicine to treat stomach ailments. Some people are employed by a company that harvests acacia for charcoal. Land access is communal, particularly where acacia growth is spontaneous; however, some local elites have successfully sought private titles for outgrower plantations of acacia for pulp (Aitken *et al.*, 2009; See Box 1 on Australian acacias in South Africa).

6. Amazizi and AmaGwane Tribal Authority areas, KwaZulu-Natal, South Africa

Extension agents promoted *A. mearnsii* in this grassland area in the mid-1900s to provide a resource for the community and reduce pressure on indigenous forest patches. There now are extensive acacia woodlots and many small (< 1 ha) mixed age stands, covering under 5% of the area. Larger woodlots are communal, under the control of the local tribal Chief; other smaller clumps of acacia are attached to particular households. The Chief was reported to have sold rights to harvest communal woodlots to external entrepreneurs. *Acacia mearnsii* is the main local source for local household energy, timber and fencing. Some people collect headloads or truckloads of woodfuel for sale in settlements and nearby areas. The cover provided by woodlots is sometimes perceived as a security risk, but also as latrine areas. When the national alien plant clearing program, Working for Water, offered employment to clear *A. mearnsii* in this area, many locals were prepared to clear acacia communal woodlots in exchange for wages.

7. Private lands, Western and Eastern Cape, South Africa

This regional category groups several localized case studies with predominantly private land (for agriculture, tourism, retirement, conservation, with generally relatively affluent landowners of white descent and some resident farm labourers) intermixed with some low-income (black or coloured) informal settlements and state-owned nature reserves. Proceeding along the coast from east to west, they include the Kouga catchment (part of the Baviaanskloof Mega-Reserve – a cluster of protected areas within a network of multiple-use private and communal lands), Wilderness (a popular holiday and retirement area), Grabouw (an apple and grape farming region) and Citrusdal (a drier, more inland citrus growing area). A variety of introduced acacias dominate unmanaged portions of the landscape, including *A. mearnsii*, *Acacia saligna* (Labill.) H.L.Wendl., *A. longifolia* (Andrews) Willd. and *A. melanoxylon*. National campaigns to improve water resources, reduce fire risk and restore native vegetation have resulted in large sums being invested in this region to clear these acacias. Landowners are well aware of these campaigns, and many citrus farmers, for example, see *A. saligna* as problematic. However, a subset of landowners in all four localities regularly employ acacia wood products for household use (e.g. woodfuel in vacation guest homes) or side-line business endeavours (e.g. selling woodfuel or mulch) and appreciate specific acacia stands for their shade (for livestock, particularly in the treeless Citrusdal) or for furniture industries (especially *A. melanoxylon*). Resident farm labourers harvest acacias for woodfuel, building and fencing material. Because of its malleability over native vegetation, youth from these areas have been known to use *A. mearnsii* to construct 'bush' shelters as part of their cultural initiation rites. Some landowners have agreements with neighbouring poor communities who clear acacia in exchange for the wood. Interestingly, a few conservation-minded landowners (in the Kouga catchment) have expressed a desire to retain stands of *A. mearnsii* for their potential role in offsetting global CO_2 emissions.

8. Cape Flats, Western Cape, South Africa

Acacia saligna and *A. cyclops* A.Cunn. ex G.Don were established in peri-urban Cape Town by 1870 to stabilize drifting sands and as fuel. Land in the area is either owned privately or by the municipality, with many informal low-income settlements. In the mid-1980s, 39% of land was moderately or heavily covered by the trees; they continue to dominate remnant open land. An important acacia woodfuel industry has developed, undertaken by poor communities from adjacent urban areas. Poles for building structures and woodfuel are used directly by poor households. In 1992, the annual turnover of the latter products was estimated at 7 and 1 million USD, respectively. As a result of perceived negative impacts on water and native biodiversity, government scientists and environmental managers have released biological control agents for both acacia species. Impact on local livelihoods remains unclear (Azorin, 1992; Higgins *et al.*, 1997).

9. Bateke plateau, Democratic Republic of the Congo

From 1987, *c.* 8000 ha of *A. auriculiformis* were planted among the vast forest plantations on this 700-m lightly settled plateau. In 1994, a development project converted the acacia to an agroforestry project, granting management rights over 25 ha plots to 300+ families from several provinces. Following a rotational system, each year a family harvests circa 2 ha of acacias for sale in Kinshasa (140 km to the west), planting corn, cassava and more acacia in the clearing. By the time the cassava is harvested, the acacias are 3 m high. Economic returns from these crops and from honey reach 2.6 million USD annually, of which 25% goes to the participant families, an income six times the urban mean (Bisiaux *et al.*, 2009).

10. Maradi region, Niger Republic

In the 1970s and 1980s, a number of projects established trials of Australian acacias across the Sahel to assess their potential as woodfuel and windbreaks (Cossalter, 1986). *Acacia colei* B.R. Maslin and L.A.J. Thomson in particular was widely planted, but initial enthusiasm for this fast growing, hardy tree was tempered by its short life span and need for wide spacing and pruning. NGO projects in the past two decades have promoted the incorporation of *A. colei* and *A. torulosa* Benth. into agroforestry systems with the goal of shielding villagers from environmental shocks like droughts. In addition to benefits for soil fertility and wind protection, villagers use the wood for poles, tool handles and fuel. Noting Aboriginal use of *A. colei* seed as food, projects have also promoted it for nutrition. Rows of acacias have been planted in over 700 plots of 0.5–1.0 ha in 44 villages in the region; the use of seed as human food exists in at least 10 villages. However, acacia adoption is limited outside areas of project intervention, and uptake of food use has been slow, because of difficulties in establishing the plants (the harsh climate, high grazing pressure and field ploughing), cultural reticence as far as new foods and farm techniques, and a lack of acacia seed markets (Rinaudo & Cunningham, 2008).

11. Tigray, Ethiopia

Since the 1970s, agroforestry projects have promoted *A. saligna* in this dry, degraded region, initially for land rehabilitation. The tree is now common in pockets of this intensively farmed landscape, where it is one of the few planted trees and crucial for the survival of local populations in recent droughts. The tree is used for fodder, soil fertility and woodfuel (Descheemaeker *et al.*, 2006; Rinaudo & Admasu, 2010).

12. Israel

Many Australian acacias were introduced to British-mandate Palestine in the 1920s and 1930s, planted on state lands by foresters to stabilize soils, reclaim or afforest lands. Of the 31 species introduced, four have become invasive, most notably *A. saligna*, but also *A. salicina* Lindl., *A. cyclops* A.Cunn. ex G.Don, and *A. victoriae* Benth. Plantings have mostly ceased (recent experiments with introduced acacias as goat fodder have not been implemented). The Israeli public considers *A. saligna* a local plant, appreciating its blossoms, yet environmental agencies are increasingly concerned with managing invasion (Dufour-Dror, 2010).

13. Côte d'Azur, France

Since the mid-1800s, dozens of Australian acacias have been introduced to southern France for largely ornamental purposes. By the 1870s, *A. dealbata*, which tolerates the region's cool climate, was well established in industries that continue to the present. Today, a small number of family farm operations cultivate an average of 1.5 ha of *A. dealbata* × *A. baileyana* hybrids for sale as cut flowers, with annual production of 550 t on 112 ha in the Alpes maritimes. In addition, the perfume industry in Grasse purchases 150–200 t of acacia blossoms from low-income collectors harvesting from the 'wild'. Finally, gardens and nurseries sell a large number of acacia cultivars as ornamentals. The tree is celebrated in the local landscape and used to promote tourism in the region. However, biologists consider it invasive in the Tanneron, Estérel and Maures massifs, as well as outside the region in Languedoc-Roussillon. Further spread is limited because of the intolerance of neighbouring alkaline soils and decadal killing frosts (Quertier & Aboucaya, 1998; Breton *et al.*, 2008).

14. Central coastal Portugal

From the late 1800s to mid-1900s, government foresters and private entrepreneurs propagated several acacia species (mainly *A. dealbata, A. melanoxylon, A. mearnsii*, *A. pycnantha,* and *A. saligna*) to supply wood products to the modernizing economy and to afforest common lands nation-wide. The forestry services introduced several acacias to the central-north coast from 1897 to the early 1940s during campaigns to consolidate sand dunes, prevent erosion and provide protection for extensive *Pinus pinaster* plantations. The favoured species was *A. longifolia*, which now covers circa 2850 ha between Pedrogão and S. Jacinto (*c.* 12% of the area), in dense stands in the dunes and interspersed as undergrowth in *P. pinaster* plantations. In the past, local communities sporadically used acacias for woodfuel, basketry, cut flower, tanbark and construction. Today, most acacias are subject to legislation aimed at controlling invasive species and prohibiting their further use and planting. Only small-scale marginal uses persist, with some interest in using acacia for woodfuel or the plant biomass industry.

15. Rio Grande do Sul, Brazil

Following policies of industrialization and import substitution, from the mid-1900s Brazil encouraged the plantation of *A. mearnsii* to supply its leather industry with tanbark (Oliveira, 1960). The number of farmers and planted area continues to grow; recent figures indicate 10,000 farmers planting about 156,000 ha in Rio Grande do Sul state (Mochiutti *et al.*, 2007). From these plantations, the tree has also spread into unused land, where it acts as a pioneer species (Mochiutti *et al.*, 2008). Landowners plant acacia to complement other farm income, selling bark to tannin extractors, wood to pulp companies, as well as charcoal and woodfuel.

16. Bio-Bio region, Chile

The southern end of Chile's Mediterranean zone was originally covered by *Nothofagus* and sclerophyllous forests. Intensive use for agriculture from the 1800s up to the mid-1900s led to high levels of erosion, leading government foresters to promote the planting of *A. dealbata* to stabilize soils. This species currently covers *c.* 5–10% of the region, especially in creeks, riversides, roadsides and abandoned fields. Called 'the Chilean wattle', it has ornamental value, is considered one of the best woodfuel trees and is used to produce charcoal for the surrounding urban areas. Some is even used in local pulp mills. Although seen as a competitor for *Eucalyptus* and *Pinus* plantations by forestry companies and as an invader of natural ecosystems (Fuentes-Ramirez *et al.*, 2010), its importance and value for local communities have not been systematically assessed.

17. Zambrana-Chacuey, central Dominican Republic

This smallholder landscape is characterized by diverse land uses, including cattle pastures, rice fields, cocoa forests and homestead tree gardens. In the 1980s, an NGO worked with a local farmers association to implement a social forestry project. In a landscape of 0.5- to 2-ha smallholdings, a majority of farmers adopted *A. mangium*, growing small woodlots or planting the tree on field edges or individually. The tree's main use was for timber in national markets; a sawmill was set up locally in 1993. By that time, 800,000 trees were growing in the 250 km^2 region. Some farmers resisted acacia on their land, because of implications on labour and control. Divergent local opinions – reflecting gender, class and other interest groups – struggled with how the project strengthened the hand of large landowners and privileged monocrop plantings over more diverse farm forests (Rocheleau *et al.*, 2001).

18. Maui, Hawai'i, USA

Hawaiian authorities introduced numerous trees from the late 1800s through the 1960s in an attempt to protect degraded watersheds (Woodcock, 2003). In upland Maui, some 65,000 *A. mearnsii* seedlings were planted on forest reserves. Plantations were harvested as fuel for boilers in sugar refineries; other proposed uses such as tanbark and fence posts (Zschokke, 1930) did not see large uptake. The species has not been commercially utilized for over two decades, and it is proliferating in reserves, along roads and in disturbed areas. Ranchers appreciate individual large trees as shade for cattle, but not invasive thickets.

DISCUSSION

Introduced Australian acacias provide important economic and subsistence resources to people around the world. The case studies show, however, that there are strong variations in how societies and communities organize and perceive that use. Table 3 generalizes the main patterns in how key biophysical, social and familiarity factors shape these differences across the case studies. Many of these factors are highly interrelated, operate at multiple scales and depend on particular historical and geographical context (also see Carruthers *et al.*, 2011). To make better sense of them, we categorize the regional case studies into four main groupings. The groupings emerge from a qualitative assessment and comparison of the cases, based on both the case study material and our combined broader contextual knowledge. The most salient variables in these groupings are the level of economic development, the extent of commercialization and the nature of management ('wild' harvests vs. cultivation).

First, several case studies describe poor communities that are beneficiaries of specific agroforestry project interventions. In these cases, which include Niger, Congo, Ethiopia and the Dominican Republic, acacias are late 20th century introductions that require deliberate planting and tree husbandry. They are promoted by projects specifically for the livelihood benefits to local people, but also frequently because of conceptions about needs for environmental rehabilitation and reforestation.

Second, there is a clear trend across numerous case studies of people taking advantage of a valuable resource already present in their landscape. These cases generally involve poorer elements of society (farm labourers and communal land residents in South Africa, peasant villagers in Madagascar and India) yet also include farm owners and other entrepreneurs (e.g. in Western Cape or Chile) harvesting acacia for commercial gain. They rely either on 'wild' stands of acacia that self-reproduce or on formal plantations to which they can negotiate access. Where reliance is on 'wild' stands, acacia diffusion occurred a fairly long time ago, allowing time for naturalization and invasion. The resources contribute strongly to the household economy, either directly as woodfuel and construction wood or indirectly through sale.

Third, a number of cases describe small- and mid-scale participants in a formal forest products industry, including primarily Vietnam and Brazil, but also relevant in parts of South Africa (de Neergaard *et al.*, 2005) and to a few private entrepreneurs in the Palni and Nilgiri Hills. Government and industry initiatives in establishing and promoting industries centred on tannin extracts, construction wood or pulpwood create markets for full-scale commercialization of valuable forest products. These activities provide good income to households with access to land and capital necessary for initial investments.

Finally, we note a number of rich country communities dealing with the legacies of former or niche use of introduced acacias and rarely reliant on acacias for domestic uses. While minor, specialized uses may continue (in Réunion's artisanal geranium trade, in France's cut flower and perfume industry), in general the trees no longer serve any utilitarian function aside from ornamental and are perceived, at least by scientists and some land managers, as weeds. In addition to Hawai'i, Portugal and Israel, some portions of the Western Cape private lands fit this category.

A problem with these categorizations is that different individuals within a case study (man, woman; richer, poorer) may fit different categories. The great disparities in South African society, notably, allow elements of its case studies to span several categories. Furthermore, in several cases (South Africa and southern India), formal acacia uses by plantations are accompanied by informal uses of great importance (but small monetary value) by adjacent residents.

CONCLUSIONS

The value of introduced Australia acacias to people around the world is chiefly linked to their utility. Our qualitative case study analysis demonstrates that economic development (and concomitant local levels of need), presence of acacia in the landscape (for diverse original purposes) and the character of opportunities for commercialization are key conditions that shape the value of acacias to society. Acacia uses extend from the expected major applications – woodfuel, charcoal, minor construction timber, industrial pulp and tannin – to a wide variety of innovative minor uses, including perfume extracts or the use of ash in homemade soaps. For many poor people, acacias provide heat or cooking fuel that they could not otherwise afford, serve as accessible and strong poles, beams and furniture components and add fertility to infertile soils. For specialized smallholding families and entrepreneurs, acacia products supply a stream of income from industrial and commercialized products. Furthermore, the trees tend to be appreciated for aesthetic and ornamental reasons. However, negative aspects of the introduced acacias are perceived in some cases by those who do not reap the benefits (like less powerful community members), by those whose land uses are affected (like graziers losing pasture to dense infestations of acacia) and by biologists, environmental managers and community members concerned with the impacts of invasive species on native biota, water resources and fire regimes.

In a global context where introduced acacias are increasingly managed as problematic invasives, the results of this survey suggest conclusions somewhat at odds with each other. First, acacias play a role in the economic development of different regions, both industrially and by providing useful products to poorer segments of society. Yet as economic growth continues (at least from the historical evidence in the case studies), non-industrial exploitation declines and, in some particular cases, industrial exploitation evaporates, leaving large acacia populations poised to expand in the landscape (or in densely populated areas like Java, to be replaced by other crops: Berenschot *et al.*, 1988). If control of invasive aliens is a policy goal, the above situation suggests early control efforts. However, such control efforts will then necessarily impact poor communities, for it is in poorer communities that dependence on acacias is highest. Furthermore, in many places, demand for industrial acacia products like solid wood and chips is strong and for pulp is increasing (Griffin *et al.*, 2011). Thus, efforts to control invasive acacias must give explicit attention to the needs of all sectors of society. In South Africa, an initial framework for a national strategy to deal with Australian acacias is attempting to integrate diverse needs and interests (van Wilgen *et al.*, 2011). There is considerable scope for different regions to learn from experiences elsewhere in the world in the search for pragmatic solutions that balance multiple interests and future unknowns.

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BIOSKETCH

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