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Biological invasions and biocultural diversity: linking ecological and cultural systems

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SUMMARY

Study of the ecological and economic effects of invasive species has paralleled their progressively pervasive influence worldwide, yet their cultural impacts remain largely unexamined and therefore unrecognized. Unlike biological systems, where the ecological consequences of biological invasions are primarily negative, from an ethnoscientific standpoint, invasive species' impacts on cultural systems span a range of effects. Biological invasions affect cultural groups in myriad, often unpredictable and at times contradictory ways. This review groups case studies into a conceptual matrix suggesting three categorically different cultural impacts of invasive species. Culturally impoverishing invasive species precipitate the loss or replacement of culturally important native species and their associated cultural practices. Culturally enriching invasive species augment cultural traditions, through their inclusion in lexicons, narratives, foods, pharmacopoeias and other tangible and intangible ends. Culturally facilitating invasive species can provide continuity and reformulation of traditional ethnobiological practices. An understanding of the processes by which invasive biota become culturally enriching, facilitating, or impoverishing can contribute to articulating interdisciplinary programmes aimed at simultaneously conserving biological and cultural diversity.

Keywords: alien species, biocultural diversity, biological invasions, cultural diversity, diaspora, exotic species, indigenous, introduced species, invasive species, traditions, weeds

INTRODUCTION

Invasive species affect both biological and cultural systems. Biological invasions have emerged as a major ecological and environmental policy issue, displacing native species in both terrestrial and marine habitats at unprecedented rates (Mack *et al*. 2000; UNEP [United Nations Environment Programme] 2001; Simberloff *et al*. 2005). Despite ongoing conceptual debates defining native versus exotic (or 'alien') species (Colautti & MacIsaac 2004; Townsend 2005; Larson 2007; Warren 2007), in general the term 'invasive species' refers to anthropogenically introduced biota that rapidly become naturalized, widespread and dominant in new habitats, harming ecosystems, economies or human health (NISC [National Invasive Species Council] 2006). Although all invasive plants are 'introduced,' only a portion of introduced species become invasive. Invasive species are ecologically advantaged by abiotic and biotic regime changes, genetic adaptability, phenotypic plasticity, allelopathic properties, strong reproductive capacity and lack of historically-associated predators in their new habitats, enabling them to displace and extirpate native species *in situ*, eventually changing community assemblages and altering ecosystem processes in aquatic and terrestrial habitats (Occhipinti-Ambrogi & Savini 2003; Padilla & Williams 2004; Van Driesche & Van Driesche 2004; Sax *et al*. 2007). Eighty-four per cent of the world's coastal ecoregions have been invaded by at least one species (Molnar *et al*. 2008). In the USA, 49% of federally listed species are endangered by introduced biota and extinctions caused by introduced species are 'second only to those caused by habitat degradation' (Simberloff & Strong 2000). New Zealand has roughly the same number of escaped exotic species as it does natives (Williams & West 2000); similar figures are true for plant life in Hawaii, Mauritius and the Galapagos (Baskin 2002). A survey of 31 fish introductions in Europe, North America, Australia and New Zealand found that in 77% of the cases, native fish populations were reduced or eliminated following the introduction of non-native fish (Ross 1991, p. 363). With species naturalizations increasing worldwide, global 'homogenization' threatens both biological and cultural diversity in even the most remote locales (Olden *et al.* 2005; Sax *et al*. 2005).

Biological invasions are a significant economic issue, causing enormous losses in agricultural, conservation, fisheries, forestry, transportation and tourism sectors worldwide (Pimentel 2002); with annual damage costs estimated at US$ 13 billion for Australia, US$ 30 for Brazil and US$ 143 billion in the USA (Shine 2006). However, the cultural impacts of invasive species remain largely uninvestigated, although biological invasions affect culturally important flora and fauna, including medicinal and ceremonial plants, totemic animals such as salmon and sacred wildland gathering sites and native peoples themselves. For example, within scientific reviews of bioinvasions (see Williamson 1996), the disastrous cultural impacts of invasive pathogens on indigenous peoples is curiously absent: the

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ecological and economic impacts of exotic species on native species, ecosystems or national industries are detailed without equivalent citations for the genocidal consequences of exotic infectious diseases on Native cultures. Invasive species affect cultures in myriad, often unpredictable and even contradictory ways by displacing culturally significant native biota, augmenting the range of potentially useful biota and providing biocultural continuity to diaspora communities. Interdisciplinary studies linking biological diversity, cultural diversity and biological invasions are only beginning to emerge (Nuñez & Simberloff 2005; Wertz 2005; Díaz *et al.* 2006; Redford & Brosius 2006; LaDuke 2007; Pfeiffer & Ortiz 2007). Critical questions remain unaddressed: how have biological invasions impacted social systems and cultural landscapes? Do invasive species threaten native customs in the same way they displace and extirpate native species? How are indigenous and immigrant societies responding to biological invasions? In an age of accelerating cultural erosion, a deeper understanding of the links between invasive species and cultures is urgently required.

A few philosophers, historians and social scientists have addressed the sociocultural dimensions of invasive species, often with contentious results (Woods & Moriarity 2001; Clayton 2003; Beinart & Middleton 2004; Robbins 2004; Helmreich 2005; Larson 2005), as the destructive ecological impact of bioinvasions makes it difficult for many scientists to remain objective. Yet ignorance of the multifaceted cultural aspects of biological invasions is counterproductive. Invasive species are anthropogenic phenomena. Motivations driving the adoption and persistence of organisms that are ecologically, economically and culturally detrimental merit cross-disciplinary investigation. Economic, cultural and sentimental attachment to invasive species and concerns over health impacts of broad-spectrum pesticides used to control invasive species often impede management programmes, leading to heated conflicts between government land managers and local residents.

This paper investigates the global sociocultural dimensions of invasive species. Given the tremendous scope of bio-invasions, our review is not exhaustive; our conceptual framework centres on seventy case studies extracted from paper and electronic texts within academic, popular and grey literature, database queries and library accessions. Only positive 'hits' (i.e. confirmed reports of invasive species having an observable cultural impact) were included. Given our sociocultural focus, we only consider invasive species present in anthropogenically influenced landscapes (i.e. areas cultivated, managed, foraged, hunted or fished by local populations) within Native (both indigenous and diasporic) and cosmopolitan societies.

We define 'culturally invasive' biota as non-native organisms or genetic material that have ecologically displaced or extirpated native biota, resulting in a detectable cultural impact on resident societies. Our conceptual approach proposes three categories of culturally invasive biota describing the predominant types of impacts wrought by biological invasions on cultural systems. 'Culturally impoverishing' invasive species precipitate the loss or replacement of culturally important Native species and their associated traditions. 'Culturally enriching' invasive species augment cultural traditions, through their inclusion in lexicons, narratives, foods, animal feed, fibres, fuels, medicines and other tangible and intangible ends, including spiritual, ceremonial, magical, social, decorative, aesthetic, symbolic, agricultural and environmental uses. 'Culturally facilitating' invasives are culturally salient biota whose presence in alien landscapes allow diaspora communities to perpetuate their ethnobiological interactions with nature, enabling post-migration cultural continuity.

These categories are not set points along a continuum; instead, they are fluid and mutable and can be theoretically portrayed as three apices on a triangular matrix, similar to the typology gradient used to define sand-silt-clay ratios in soil science (Shepard 1954). Our typology provides conceptual, but not deterministic boundaries: invasive species can pertain to one, two or all three categories at given points in time, depending on the historical and geographical circumstances surrounding their introduction and dispersal. As sociocultural systems are both dynamic and heterogeneous, the impact of bio-invasions can vary within a cultural group and may depend on who is performing the assessment. Our categories serve as intellectual pointers within a theoretical territory that has yet to be charted. The goal of this study is to encourage scholars and practitioners to consider the multifaceted, and often puzzling, connections linking biological invasions and cultural systems, in order to better conserve our collective biological and cultural heritage.

HISTORICAL FRAMEWORK

Biotic migration, via biological speciation, climatic fluctuation and tectonic movements, is a constant feature of Earth's dynamic biogeography. Yet, although ecological and social systems are constantly evolving and changing over time and space, our generation has witnessed an explosion in the transference of non-native species and a concomitant revolutionary alteration of physical and cultural landscapes (Baskin 2002). Since the era of cross-oceanic exploration, the pace and scale of 'irreversible bio-invasions' (Warren 2007) via transcontinental interchanges has increased exponentially through human introduction, spread and retention of biologically invasive species. With the exception of waif-dispersed strand species, nearly all plant and animal introductions during the last 500 years can be assumed to be of human origin (Mack & Lonsdale 2001).

From an environmental standpoint, the impacts of invasives range from relatively benign to disastrous. The cultural record is more ambiguous and complex. Invasive species bring a range of consequences to local cultures, at times irrevocably altering the agricultural regimes, cuisines and cultural practices of emigrant regions. The historical record reveals early patterns of biological invasions associated with human settlements:

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chenopod (*Chenopodium* sp.), purselane (*Portulaca oleracea*) and oxalis (*Oxalis stricta*) have been uncovered in remains dating to the early Woodland (1000 years BCE) and Late Archaic (R. Bonzani 2002, personal communication). The invasive herb, *Plantago major,* a disturbance species native to Eastern Europe that advanced as glaciers retreated, had significant medicinal value amongst the Greeks and Romans (Stannard 1972; Jones 1994). Ancient Mediterranean societies introduced exotic fauna for sport or consumption, a number of which, namely cats, African snails and freshwater fish, had invasive tendencies (Hughes 2003). Botanical hitchhikers, including viral and fungal pathogens, some of the most notorious biological invasions (such as the Irish potato famine) have inevitably accompanied the introduction of cultivated plants. The migration of Europeans and their livestock and pets, and Polynesians and commensals, including cattle, sheep, goats, horses, cats, mustelids, rabbits, pigs and rats (and their accompanying diseases), led to profound changes in the landscapes and sociopolitical trajectories of human populations (Baskin 2002).

Certain invasives have become so thoroughly incorporated into local systems they are considered 'native' or culturally iconic. These include kudzu (*Pueraria montana* var. *lobata*) in the Southeastern USA, wild horses in the western USA, invasive mustards and grass species dominating the 'golden hills' of California (USA), feral pigs (*Sus scrofa*) in Hawaii (USA), water hyacinth (*Eichhornia crassipes*) in riverways throughout Asia, Africa, Australia and the Americas, and sport fishing industries based on introduced trout and other predatory invasive species. Invasive pigs have long been a mainstay of hunters throughout the Pacific and invasive freshwater fish are a popular dietary supplement for immigrant communities in the USA. In Australia, Aboriginal communities use invasive plants and animals for bush tucker, medicines and as traditional toys (Low 2002).

Examining historical patterns and current adaptations involved in cross-cultural invasive species introductions illuminates how invasive biota become culturally impoverishing, leading to the loss or replacement of both native biota and associated cultural traditions, culturally enriching by augmenting cultural traditions, or culturally facilitating by helping to retain cultural practices. Because records of species diffusion and subsequent cultural interactions are scattered, we cannot estimate the impact of invasive biota on cultures worldwide with precision. Instead, we examine the conceptual links between invasive and native biota via case studies of invasive flora, fauna and microorganisms with a demonstrable effect on the cultures of historical and modern societies.

BIOLOGICAL INVASIONS AND CULTURAL LANDSCAPES

Indigenous societies worldwide derive their cultural identity and physical wellbeing through intimate relationships with native biota (Posey 1999; Grim 2001; Stepp *et al.* 2002). Terrestrial and aquatic communities of wild, semi-domesticated and domesticated species have been used, tended and conserved by people for centuries, resulting in culturally and ecologically unique mosaics. These mosaics can be described as living landscapes of biological and cultural evolution; native species form the basis of cultural practices that change over time, just as indigenous cultural practices result in genetic and ecological changes to native species (Dounias 2001; Turner *et al.* 2003; Anderson 2005). When biological invasions lead to a restructuring of terrestrial and aquatic communities, while simultaneously impacting culturally significant biota, the invasions can also restructure the socio-cultural systems reliant on native bioresources. Cultural diversity suffers when invasive species threaten or extirpate native species of cultural importance, especially for indigenous groups working to revitalize endangered traditions. For example, destruction of Native American cultural landscapes through invasive domesticates brought by European settlers led to the loss of harvesting sites including bison grazing grounds, clam banks, grasslands and riverbanks, and habitats for foods and medicines such as wild-managed camas (*Camassia* spp.) and bitterroot (*Lewisia rediviva*) (Cronon 1983; Lewis 1995; Warren 1996; Bonnicksen *et al.* 1999). In the Pacific, the voracious crown-of-thorns starfish (*Acanthaster planchi*) reef invasion has caused massive coral dieback and the loss of viable habitat for hundreds of reef species, culturally damaging islander communities (Crosby *et al.* 2002, p. 123). Successive waves of invasions in Lake Victoria, beginning with the Nile Perch (*Lates niloticus*) in the 1960s and continuing with the water hyacinth (*Eichhornia crassipes*), have driven hundreds of native fish species to extinction and exponentially increased the incidence of snail- and mosquito-borne diseases, affecting the health and welfare of millions of Central Africans (Bright 1998).

These examples demonstrate how cultural landscapes can be restructured by biological invasions within 1–2 human generations, a time period too short to allow most communities to adapt. These invaded, or invasive-species-dominated, habitats deprive communities of a substantive biodiversity base for maintaining economic and cultural resilience. Just as multiple species performing similar ecological functions help buffer ecosystems, a diversity of species fulfilling similar cultural functions help maintain cultural systems. Negative impacts of invasive biota on native biodiversity (species and ecotypes) contribute to the attrition of cultural diversity (culturally unique knowledge and practices) among native peoples by reducing the abundance of, and restricting access to, culturally important natural resources. In the Northwestern USA, the Yakama have declared a state of emergency and are adopting drastic measures to combat spruce budworm (*Choristoneura fumiferana*) in tribal forests where it affects multiple cultural resources (USDA [United States Department of Agriculture] 2003). Native oak trees (*Quercus* spp.), long revered by Native Americans as a basic food source and the focus of modern celebratory acorn harvest festivals, are dying by the tens of thousands along the USA Pacific coast due to sudden oak death caused by the invasive

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pathogen *Phytophthora ramorum* (Rizzo & Garbelloto 2003). In California, increased populations of invasive plants such as starthistle (*Centaurea solstitialis*) and scotch broom (*Cytisus scoparius*) are invading sacred groves and ancestral gathering grounds, displacing plant species such as redbud (*Cercis canadensis*) and deergrass (*Muhlenbergia rigens*) used by native basketweavers (Pfeiffer & Ortiz 2007).

Maintenance of biocultural diversity and cultural resilience is dependent on a society's continued access to culturally salient native biota (Pfeiffer & Ortiz 2007): when invasive species diminish cultural access, the challenges faced by community members in retaining or reviving their ancestral traditions are multiplied. Cultural erosion occurs when ancestral traditions, including the naming, use, understanding of, management and reverence for native species, are not passed on in a meaningful form to younger generations. Physiologically armed invasive plants such as starthistle, cocklebur (*Xanthium strumatium*) and stinging nettle (*Urtica gracilis*) present a physical barrier to accessing and collecting native basketry plants, a serious concern as most expert basketweavers (the primary instructors for younger weavers) tend to be 60–90 years old (Pfeiffer & Ortiz 2007). In the Great Lakes region of USA and Canada, the invasive emerald ash borer beetle (*Agrilus planipennis*) has killed millions of native black ash trees (*Fraxinus nigra*), endangering the ancestral basketry traditions of the Chippewa, Ottawa, Odawa and Potawatomi (NRCS [Natural Resource Conservation Service] 2006). In arid lands of the Southwestern USA, invasive tamarisks (salt cedar, *Tamarix* spp.) have significantly diminished populations of culturally important native plants including cottonwood (*Populus fremontii*) and willow (*Salix exigua, S. lasiandra*) through water deprivation (Bindell 1996; USDA-NRCS 2008). On Hopi lands, tribal elders supervise the uprooting and replanting of plants including sand reed (*Calamovila gigantea*), willow and yucca (*Yucca* spp.) closer to reservation lands where they can be better conserved (E. Salmon, personal communication 2003).

Wherever a biologically invasive plant species displaces a culturally important native species, it can cause a ripple effect by displacing related traditions in the cultural 'storyscape' (Pretty 2002). A cultural storyscape is the place-based intergenerational narrative maintained by a native society; the storyscape encompasses both tangible (visible, practical) and intangible (internal, philosophical) traditions. Expressions of biocultural diversity contained in a cultural storyscape include folk taxonomies, ethnobiological practices and ancestral stories and songs based on local natural resources. Invasive species affect cultural storyscapes by altering the character of sacred or ritual sites and displacing or diminishing the growth of ethnobiologically important native species in ancestral gathering sites (for food, medicine or crafts. The degree of impact varies from barely perceptible or manageable effects, to the point where certain cultural traditions become extinct.

For example, in the Pacific Northwest, Himalayan blackberry (*Rubus discolor*) has invaded Karuk ritual sites (Pfeiffer & Ortiz 2007) and, in the Southeastern USA, foraging feral pigs damage Native American historic sites and burial grounds (Frazier 2005). In Australia, feral pigs affect Northern snake-necked turtle (*Chelodina rugosa*) populations, threatening Aboriginal harvesting practices and disrupting the timing and frequency of related cultural activities (Fordham *et al.* 2006). In New Zealand, invasive species negatively impact Maori *taonga*, physical and metaphysical resources including ancestral lands, waters, gathering sites and sacred (spiritually endowed) places known as *waahi tapu* (Given 1995; New Zealand Conservation Authority 1997). A parallel situation is occurring in Central Australia, where 'camel plagues' are destroying ancient, co-evolved biocultural relationships and associated values (B. Mackey, personal communication 2008). In Malesia and Melanesia, an invasive soilborne fungus (Panama disease, *Fusarium oxysporum*) and an invasive bacterium (blood disease, *Pseudomonas celebensis*) are threatening native bananas used in traditional foods, cooking rituals and ceremonial dress (Baskin 2002; Koeppel 2005).

Escaped biocontrol agents have their own cultural consequences. The cane toad (*Bufo marinus*), introduced in Australia to combat sugar cane pests, became a major invasive species affecting native fauna consumed by aboriginal communities. Cane toad invasions, often in plague proportions within ancestral lands, have sharply decreased populations of species of religious or cultural significance, including wild-harvested freshwater crocodiles, goannas and snakes, defiled sacred waterholes and polluted natural springs. Aboriginal elders worried about the potential health risks of the toad's toxicity have altered their ceremonies to ask the spirits for the return of their totem species (van Dam *et al.* 2002; Horstman 2003). Cactus moth (*Cactoblastis cactorum*), a biocontrol agent introduced to control exotic prickly-pear cactus (*Opuntia* spp.) on Caribbean islands, has spread to Florida where it threatens native *Opuntia* spp. Scientists fear its spread to Mexico, where it would threaten > 50 endangered native *Opuntia* spp., significant cultural resources for Mexicans used in food, fodder, pharmaceuticals and cosmetics, and the host plant for the cochineal dye industry (Zimmermann *et al.* 2000; Hoddle 2004).

Indirect effects of invasive species also have cultural repercussions, such as toxic chemicals used in California to mitigate biological invasions on forest lands, agricultural fields and public byways negatively affecting the wellbeing of wild-harvested food and basketry plants and the Native Americans reliant on those plant resources (Mackenzie 2003). Pesticide drift onto native plants used in traditional basketry (and gathered on public lands) stunts plant growth and causes physical deformities, rendering the plant material unusable. Washoe, Shoshone and Paiute basketweavers in the Western USA reported that basketry plants exposed to pesticides are killed off or remain deformed and brittle, with twisted shoots and rotten pith (Fulkerson 1995, Dalrymple 2000). Basketweavers' chronic exposure to pesticide drift is an issue of deep concern, not only for the health of the weavers, but also for the health of the basket (Indian

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Country Communications 1995; O'Malley 2002; Peña 2002; CIBA [California Indian Basketweavers' Association] 2002, 2004). Because many baskets are used for sacred purposes or given as gifts to vulnerable members of Native communities (for example as medicine baskets or infant cradleboards), pesticide-laden basketry material is deemed both sacrilegious and detrimental to the recipient's health.

In South and Southeast Asia, introduced South American weeds such *Chromolaena odorata* and *Lantana camara*, promoted as agroforestry crops by agricultural extension agents, yet toxic to livestock, are invading and taking over *alang-alang* (*Imperata cylindrica*) fields used for livestock grazing and thatch gathering (Monk *et al.* 1997; Potter 1997). The ecological transformation of these traditionally managed grasslands threatens agrarian societies heavily dependent on draft animals and wild-collected resources in their agricultural, economic and social systems. In India, where lantana invasions of millions of hectares of croplands, pasturelands, village perimeters and forests have displaced species used for food, animal feed and fuel, female community members need to walk further to wild-harvest bioresources and, in some instances, give up farming altogether (Shiva 1996).

Ironically, native alang-alang itself has been characterized as an invasive species for decades, prior to more recent research demonstrating that it has been historically managed by forest-based communities in Asia for centuries (Potter *et al.* 2000; Dove 2004). *I. cylindrica* is used ritually by the Balinese (Rifai & Widjaja 1979) and the Karen of northern Thailand (Potter 1997) and is employed throughout the region to thatch and adorn the roofs of bamboo huts. Alang-alang fields are decreasing throughout Indonesia; on Java the coverage has decreased from over 30% at the beginning of the 20th century to current levels of less than 2% (Garrity *et al.* 1997); in Eastern Indonesia the increasing scarcity of alang-alang is forcing families to purchase roofing material for the first time (Potter *et al.* 2000; J. Pfeiffer, personal observation 2006).

Culturally important native aquatic species have become severely endangered in freshwater and marine systems where non-native fish were introduced for sport (for example in California, Chile and New Zealand) and where ship ballast introduced invasive organisms. These extirpations negatively impact indigenous groups reliant on wild-harvesting of aquatic species. In the Southwest USA, invasive fish in Salt River within White Mountain Apache tribal lands pushed the culturally significant native Apache trout (*Salmo apache*) to the brink of extinction, forcing the tribe to implement invasive species control and ecosystem rehabilitation (USFS [United States Forest Service] 2005). Escaped farmed Atlantic salmon (*Salmo salar*) from the aquaculture industry in the Pacific Northwest are threatening wild salmon (for example chinook, *Oncorhynchus tshawytscha* and coho, *O. kisutch*) through interbreeding, competition and disease transmission (Naylor *et al.* 2005). Native salmon are of such significant cultural and spiritual importance to tribes throughout the region that it is impossible to conceptualize tribal life without salmon (Hoveman 2002; Gerwing & McDaniels 2006). The invasive European green crab (*Carcinus maenas*) and zebra mussel (*Dreissena polymorphia*) are displacing marine and freshwater mussels (Lydeard *et al.* 2004) on native harvesting lands throughout the USA. Molluscs have provided American tribes with food and shells for ornamental and ceremonial ware for centuries. Shellfish harvesting continues by tribes (such as the Passamaquoddy, Suquamish, Swinomish and the Penobscot Nation) and immigrant communities (Asian and Pacific Islander) on reservation and public lands in the Great Lakes basin and the Atlantic and Pacific coastlines, but tribes are deeply concerned about invasive species and heavy metal contamination (Fried 1998; Judd *et al.* 2005).

In New Zealand, freshwater invasive aquatic species such as giant gunnera (*Gunnera manicata, G. tinctoria*), Senegal tea (*Gymnocoronis spilanthoides*), *Egeria densa* and *Lagarosiphon major* displace culturally important species for the Maori including flax (*Phormium tenax*) and edible watercress (*Lepidium sativum*); invasive trout and catfish cause populations of edible freshwater crayfish (*koura*) and crab, dwarf inanga, giant kokopu, brown mudfish and eels to decline (Environment Waikato 2006). In marine systems the invasive brown algae *Undaria pinnatifida* modifies coastal habitats, smothering and displacing paua shellfish, mussels and other food sources of value to the Maori and other seafood gatherers (Taranaki Regional Council 2006). Given the Maori's intimate cultural and historical relationships with wetlands and waterways, the destruction and loss of these *taonga* species has had a dramatic effect on the values and identity of Maori (Environment Waikato 2006). Introduced rabbits in New Zealand dig up burial grounds and eat culturally significant plants including *Desmoschoenus spiralis* (*pingao*), a rare coastal dune sedge used as weaving material (New Zealand Ministry of Agriculture and Forestry 1997).

The most recent, and perhaps most politically contentious biological invasion, is the phenomenon of genetic material, including genetically modified organisms (GMOs) originating from transgenic crops, contaminating centuries-old heirloom crops in the Americas and Asia. Documented cases of the ingression of genetic material from laboratory-engineered industrialized varieties of maize (*Zea mays*) or rice (*Oryza sativa*) into indigenous landraces have led to serious concerns about the genetic pollution and eventual loss of ancestral crop lines by native peoples, including maize farmers throughout Mexico and wild rice (*Zizania aquatica*) gatherers such as the Anishnaabeg (Ojibwe) of north-central USA (Wertz 2005; Soleri & Cleveland 2006; La Duke 2007). In eastern Indonesia, only traditional varieties of rice are used ritually; no ceremonial practices are associated with industrialized rice varieties (Pfeiffer *et al.* 2006).

Genetic contamination negatively affects both biological (genetic) and cultural diversity by altering the available gene pool for indigenous plant breeding practices. The complexity and unpredictability of potential subsequent genetic effects of transgene flow (Ellstrand 2003) have caused deep concern for indigenous societies who revere many food plants as

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ancestors (Gepts 2005; Wertz 2005). Traditional landraces of staple food crops including maize and rice are of critical cultural and economic importance to rural communities who have developed and maintained a rich storehouse of agrobiodiversity underlying countless American and Asian cultural systems. Maize and rice are intrinsically bound to indigenous beliefs and stories of origin, artwork and handicrafts, and ceremonial rituals and social gatherings, and are the source of tens of thousands of ethnobotanical activities (González 2001; Hamilton 2003).

Yet the most devastating cultural impacts of invasive species have been that of introduced diseases, such as influenza, smallpox, syphilis, measles, tuberculosis, scarlet fever and vivax malaria, on millions of Native peoples, producing 'catastrophic reductions in population and associated social breakdown' in the Americas (Mitchell 2003, p. 173) and 'intense cultural disorientation' in Aboriginal Australia (Carey & Roberts 2002, p. 822). Thousands of cultural groups were radically altered, from the Wiradjuri of New South Wales, who invented new rituals to deal with smallpox epidemics (Carey & Roberts 2002), to the 'total collapse of village life' among the Yanomamo of Brazilian Amazonia (Wirsing 1985, p. 311).

Cultural enrichment and facilitation

The European Age of Exploration heralded a biogeographical exchange between Asia, Africa, Oceania and the Americas of unprecedented proportions (Crosby 1972; Low 2002, Beinart & Middleton 2004). Domesticated grains, vines, fruit trees and root crops were widely dispersed and firmly established by the late sixteenth century. Kitchen garden floras such as esculents, potherbs, medicinals and ornamentals were carefully transplanted from continent to continent allowing, in many cases, European settlers and successive immigrants from Africa and Asia to recreate a semblance of their native ethnoflora (Henkel 1904; Viola & Margolis 1991; Shaw 1992). Weeds increasingly marked the myriad paths of exploration, colonization and associated habitat alteration. So prodigiously invasive were some weedy taxa, such as *Erodium cicutarium* (redstem filaree), that they appear to have preceded the first major waves of European immigrants (Mensing & Byrne 1998). The outcome of the Columbian Exchange in plant movements, intentional and accidental, was nothing less than a wholesale floristic homogenization of the humanized landscapes of the tropical and temperate zones (Crosby 1972), one that dramatically augmented existing useful native species, particularly healing floras.

The 'cultural enrichment' to Native societies of this floristic reorganization process has been largely overlooked by invasive species specialists. Where biologically invasive plants have been present for more than three generations (at least 100 years), many have become culturally enriching through their incorporation into local cuisines, pharmacopoeias and rituals. Weedy plant species are a valuable source of medicines, insecticides, cover crops and green fertilizers, livestock forage and wild-harvested foods (edible greens, tubers and fruits) for communities worldwide (Bye 1981; Bennet & Prance 2000; Pieroni 2003; Alderman 2004; Ngobo *et al.* 2004; Palmer 2004; Stepp 2004). The Kallawaya Amerindians of Bolivia use invasive species in their folk medicine, including the opium poppy (*Papaver sominferum*) and sweet fennel (*Foeniculum vulgare*), among 27 other exotic botanicals (Janni & Bastien 2004). *Erodium* sp., *Trifolium* sp. and *Verbena* sp. are eaten as nutritional greens (*quelites*) in Mexico (Vierya-Odilon & Vibrans 2001). In Southeast Asia, the invasive weed *Chromolaena odorata* was originally introduced as a cover crop; and in the Southeastern USA kudzu was introduced as a soil conservation measure and continues to be a marketed in the USA herbal medicine industry (Kirkham 2004). Invasive plants introduced by Spanish and Euro-American explorers, missionaries and settlers in the Western USA, such as oats (*Avena fatua*), ripgut brome (*Bromus diandrus*) and Himalayan blackberry, have been incorporated into the diets and medicinal practices of several dozen Native American tribes (Strike 1994; Moerman 1998). The cosmopolitan weed broadleaf plantain (*Plantago major*), likely introduced into North America for its medicinal properties, was incorporated into the healing pharmacopoeias of many New World Indian groups, including the Algonkian and Omaha (Knobloch 1996; Moerman 1998). Broadleaf plantain now enters into indigenous pharmacopoeias throughout the temperate and tropical worlds (Samuelsen 2000).

The 'culturally facilitating' association between alien biota and immigrant human communities is particularly striking. In myriad cases, salient and often useful plants left behind during human migration are rediscovered in the disturbed habitats of their new lands. Thus, whereas Guatemalan exiles in southern Mexico lost much of their subsistence plant knowledge, they retained understanding of medicinal plants due to the presence of weedy exotics (Nesheim *et al.* 2006). Among Mexican migrants to USA (Waldstein 2006) and Sikhs to UK (Sandhu & Heinrich 2005), traditional use of medicinal species perseveres in part owing to the presence of introduced kitchen garden plants and weeds. During the colonial period, enslaved Africans in Brazil quickly recognized the invasive castor bean (*Ricinus comunis*) and reincorporated it into their healing rituals. Likewise the aromatic tuber of purple nutsedge (*Cyperus rotundus*), an invasive plant of almost global dimensions (Bendixen & Nandihalli 1987), is chewed by people in Nigeria who seek to influence others by their speech. This and other magical uses diffused to Brazil during the African slave trade, allowing Yoruba descendents and later freedmen to reconstitute the ethnobotanical traditions of their forebears (Voeks 1997).

Invasive species also create changes in interior cultural landscapes containing 'intangible' cultural traditions, such as narratives and lexicons, as cultural encounters with novel invasive biota creates lexical challenges. This is the case for both diaspora people encountering familiar species in new lands and indigenous peoples being 'invaded' by exotic organisms. In either case, these new organisms are often

lexically designated by their supposed place or culture of origin. Confronted with the ubiquity of invasive New World pigs, Mayan people eventually surrendered their original name for peccary, *k'ek'en*, and renamed native peccaries *k'ek'en che*, or forest pig (Atran 1999). Among Mazatec mesticos in Oaxaca, Mexico, non-native weedy plants tend to have Spanish rather than indigenous vernacular names (Blanckaert *et al*. 2007). African descendents in Brazil identify familiar invasive plants of African origin by the term '*da costa*', meaning 'comes from the coast of West Africa' (Voeks 2009). This includes a host of magico-medicinal taxa, such as *folha-da-costa* (*Kalanchoe integra*) and *dandá-da-costa* (*Cyperus rotundus*). English plantain (*Plantago major*) is a cosmopolitan weed of northern European origin, often recommended as a remedy for poison. According to historical sources, Native Americans named this plant 'Englishman's foot', referring apparently to its prodigious invasiveness and its association with advancing Euro-Americans (Josselyn 1672; Crosby 1994, p. 38).

The significance of culturally enriching and culturally facilitating invasive plants underscore a fundamental feature of plant pharmacopoeias: they are associated with anthropogenic habitat disturbance. Weeds, exotic cultigens and other successional species are usually abundant, close at hand, relatively easy to harvest (compared to primary old-growth species) and rich in biologically-active secondary compounds (Voeks 2004). The medicinal usefulness of disturbed tropical habitats may be elevated compared to old-growth forest (Voeks 1996; Ankli *et al.* 1999; Berlin *et al.* 1999; Chazdon & Coe 1999; Stepp & Moerman 2001; Voeks & Nyawa 2001; Begossi *et al.* 2002). Stepp (2004) noted that weeds are over-represented in tropical pharmacopoeias up to an order of magnitude above what would be expected from random plant selection. Most Western pharmaceutical drugs are derived from tropical plants that are weedy herbs, shrubs, vines, cultigens, or second growth trees (Soejarto & Farnsworth 1989). The Madagascar periwinkle (*Catharanthus roseus*), whose alkaloids were developed into effective treatments for Hodgkin's disease and acute lymphoblastic leukemia (Pui & Evans 1998), is a weedy perennial of pantropical distribution. Successional plant species are pre-adapted not only to becoming successful invasives, but also to becoming useful elements in indigenous and diasporic pharmacopoeias.

Mixed cultural impacts

Many of the animal species introduced by colonial invaders to the Americas and the Pacific Islands have become culturally significant resources to indigenous societies. By augmenting or displacing culturally important native species, invasive fauna eventually become 'cultural substitutes' in Native diets, rituals and sense of identity: phenomena that could be viewed as either culturally facilitating or culturally impoverishing. These include feral pigs in Hawaii, the Polynesian rat (*Rattus exulans*) on New Zealand islands, wild horses (*Equus caballus*) in the Western USA and feral buffalo (*Bubalus bubalis*) in Australia and Sri Lanka.

Feral pigs introduced from Polynesia in 750 AD are part of indigenous Hawaiian cultural rituals, including social festivities (for example *kalua* pigs roasted in traditional *imu* pits for *luau*), offerings to Pele and hunting parties (Nimmo 1986; Oliver & Brisbin 1993; Asia Forest Network 2007). Yet the pigs' destruction of fragile native ecosystems containing food and medicinal plants threaten other elements of native Hawaiian culture (Maguire 2004). The Polynesian rat, considered a key component of tribal identity for the Ngati Wai Maori in New Zealand, threatens endangered species and in certain instances has brought the New Zealand Department of Conservation in conflict with the tribes, an echo of similar conflicts over feral pigs within Hawaii (Russell 2004; Towns *et al.* 2006). In North America, horse adoption by some tribes led to a range of positive and negative cultural impacts: increased buffalo hunting success for the Sioux, but intertribal conflict between female horticulturalists and male horse riders of the Pawnee and the cultural dominance of nomadic horseback tribes over more sedentary groups (Warren 1996).

In Kakadu National Park (Australia), where water buffalo, horses and pigs have become invasive, the indigenous Jawoyn people express distinct cultural relationships with each species. Although the water buffalo displaced edible native biota in freshwater ecosystems (Australian Government 2005) and pose a threat to sacred sites, Jawoyn elders believe the buffalo 'belong' to the land owing to their importance as bush tucker (Robinson *et al.* 2005). The Jawoyn are also culturally attached to introduced horses, given their role in providing transport for social, ceremonial and economic 'country business', but they consider introduced pigs a threat, due to their more extensive negative impacts on wild-harvested plant and animal foods in a wide range of ecosystems. In Sri Lanka, where feral water buffalo threaten mangrove rehabilitation projects adjacent to areas where local herdsmen have managed the buffalo for over 5000 years, villagers 'rescue' captured buffalo from government slaughterhouses and re-release them into local forests for karmic value (Baskin 2002; Dahdouh-Guebas *et al.* 2006). In West Papua (Indonesia) the Timor deer has become an invasive species, competing for native forage with native kangaroos. Yet the deer has become an important food source for local tribes, who use its antlers for handicrafts (Hardjanti & Zainal 2003). In the African Serengeti, introduced domestic dogs adopted by the Maasai are responsible for transmitting canine distemper to hyenas, who then pass it on to lions: yet lions remain a native species of exceptional cultural importance in the initiation of Maasai warriors (Dudley & Woodford 2005).

The varied, complex and often unpredictable cultural impacts of invasive fauna suggest the possibility of simultaneous positive and negative cultural effects. In the abovementioned cases, invasive fauna's destructive impact on native species complicates their usefulness in their adoptive cultures by threatening culturally important plants and animals. Yet as populations of useful species diminished in

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response to invasive species, savvy indigenous communities adapted their diets, hunting strategies and economic activities to accommodate the introduced fauna. Warren (1996) noted that indigenous groups capable of successfully adopting introduced species into their livelihoods demonstrate resilience ultimately beneficial to their culture's long-term survival. Nevertheless, cultural adaptation through adoption of invasive species into local traditions is not always feasible, especially within relatively short time windows.

Modern cultural concerns

Social systems and cultural considerations are often stronger motivating factors than economics in the adoption and persistence of biological invasions. Preventing invasive species introductions and mitigating those already introduced is often as much a cultural problem as an ecological one. In the USA, invasive species have culturally symbolic status as state flowers or state birds: this includes Vermont's red clover, Maryland's black-eyed Susan and South Dakota's ring-necked pheasant; while on the Maine coast the invasive European periwinkle snail (*Littorina littorea*) is considered a cultural icon (Nuñez & Simberloff 2005). Modern urban dwellers often become emotionally attached to visually attractive invasive flora: ice plants (*Carpobrotus edulis*) on Californian sand dunes, pampas grass (*Cortaderia selloana*), water hyacinth (*Eichhornia crassipes*) and morning glory (*Ipomoea* spp.) are but a few examples. Even the notorious kudzu has been featured in the popular arts (cartoon strips, country songs and the *Kurse of the Kudzu Kreature* film) and celebrated in 1930s and 1940s kudzu festivals with Kudzu Queens. The sentimental dependency on artificial natural assemblages acquired through the horticulture, aquaculture, exotic pet and aquarium trades is responsible for an unending series of invasive outbreaks: from knotweed (*Polygonum cuspidatum*) and nutria (*Myocaster coypus*) to the 'killer alga' *Caulerpa taxifolia* (Baskin 2002; Padilla & Williams 2004).

Cultural attachments to invasive species primarily attract attention in conflict situations, when biological resource managers (attempting to control ecologically damaging invasive species) are confronted by angry local citizens (protesting the decisions or methods used to remove invasive species). Conflicts are exacerbated when aggressive terminology (such as 'combating' the weeds) or subjective jargon (such as 'alien' or 'exotic') is used by resource managers or science writers. Scholars have noted the linguistic parallels with the terminology used by USA immigrant control officers, whereby the language in invasive species control communiqués appears militaristic, racist, classist and xenophobic (Gould 1998; Simberloff 2003; Sagoff 2005; Helmreich 2005; Larson 2005; O'Brien 2006). In contrast, Colautti and MacIsaac's (2004) biogeography-centred species categorization system (using terms such as residing, travelling, introduced, localized, rare, widespread and dominant) evaluates biotic populations in a non-charged fashion applicable to both native and non-native species, while accounting for spatial variation.

In contrast to academic or political programmes that ignore cultural concerns, conservation programmes that replicate indigenous resource management practices can protect both biological and cultural diversity by protecting threatened native species (DiTomaso *et al.* 1999), while simultaneously supporting Native cultural practices. Successful biocultural diversity conservation programmes involve local populations in long-term habitat restoration that links biological communities and historical indigenous land management regimes linked to those communities. Hundreds of Native cultural groups throughout the Americas, Europe, Africa, Asia and Australia have partnered with government agencies to actively rid their lands and waters of invasive species. In Australia, aboriginal tribes and park rangers jointly manage park areas for invasive plants and animals (Kakadu National Park 1999; Robinson *et al.* 2005). In Northern California, government agencies are undertaking collaborative restoration and invasive plant control programmes with local tribes using propagation, replanting or burning to promote native species used in basketry. Resource managers in Redwood National Park (USA) have reintroduced historical burning regimes to 'improve native plant establishment and diversification' and avoid 'the loss of significant cultural resources' (Underwood *et al.* 2003, p. 282). In Hawaii, traditional gatherers of native *hula* plants incorporate mechanical control of invasive species in their resource management programmes. This is a critical innovation, as gathering of certain culturally useful ferns without simultaneous weeding of invasive plants can result in localized invasive cover increase (Ticktin *et al.* 2006).

Other collaborative programmes between tribal groups and federal agencies, such as the United States Environmental Protection Agency (US-EPA) sponsored invasive species removal programmes have served to restore ecological systems and associated cultural practices while simultaneously revitalizing tribal community spirit and solidarity (US-EPA 2003). The White Mountain Apache, working in collaboration with government agencies as part of a long-term extensive habitat restoration programme based on ancestral cultural beliefs and practices, have successfully increased Apache trout populations, enabling the species to be de-listed (Long *et al.* 2003; USFS 2005). In the Klamath region, the Salmon River Restoration Council (SRRC) has worked collaboratively with local tribes and other resource users for over a decade to remove invasive plants in the Salmon River watershed (an area containing hundreds of native species actively used in food, medicines, handicrafts and rituals) using non-toxic methods and has succeeded in significantly reducing knapweed (*Centaurea repens* L.) populations and maintaining them at low levels (USFS 2000; Brucker 2004). Throughout coastal communities in California, civic groups (such as the Sierra Club and the Audubon Society) and nature societies with names such as 'Friends of Famosa Slough' (San Diego) and 'Friends of the Dunes' (Humboldt) spend thousands of person-hours annually to remove invasive plants in sensitive avian nesting habitat (www.famosa-slough.org, www.friendsofthedunes.org). In

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New England, networks of professionals and volunteers continuously update an invasive plant atlas and database (nbii-nin.ciesein.Columbia.edu/ipane/) and an invasive marine species database (www.mass.gov/czm/invasives/monitor/mimic.htm). These grassroots, community-based activities serve to build cross-cultural relationships, strengthen social networks and create a broad-based constituency of citizens with deep ties to their bioregion.

CONCLUSIONS

Biological invasions can drastically and irrevocably alter ecological and social landscapes. The consequences of biological invasions on cultural systems span a multidimensional gradient of impacts that vary spatially, temporally and intraculturally. Although many invasive species fit intuitively into the three categories we have defined (culturally enriching, facilitating and impoverishing), the inherently complex nature of biological-cultural relations means that the categories are contextual and certain culturally invasive species will defy categorization. Invasive species such as feral animals and exotic weeds demonstrate mixed cultural impacts, affecting societies in myriad, often unpredictable and at times contradictory ways. Species native or naturalized within one region become exotic invasives upon migrating to another region; species culturally meaningful to one tribe may be meaningless to another; or initially useful invasive species may be redefined as nuisances due to population fluctuations within different communities.

Understanding the cultural context of these impacts can lead to more holistic and effective ways of dealing with biological invasions. The academic obsession with native species translates into scant attention paid to the use or importance of non-native species in cultural systems of the most politically marginalized groups: indigenous and immigrant societies. Recognition of the biocultural dimensions of invasive biota can contribute to a more balanced invasive species debate, whereby the function and meaning of invasive plants and animals to Native, diaspora and modern-day communities is no longer absent from research, management, or policy considerations. We hope this article will stimulate further discussion and encourage readers to bring conceptual considerations and case studies to our attention.

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