SPOTLIGHTS

http://dx.doi.org/10.4314/mcd.v9i2.2

Approaching invasive species in Madagascar

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ABSTRACT

While a number of plants, animals, and insects in Madagascar have been called 'invasive', the topic of invasive species has until recently received less attention here than in other island contexts. Some species, often alien to Madagascar and introduced by humans, have expanded their range rapidly and have had both negative and positive effects on landscapes, on native biodiversity, and on livelihoods. Examples include the prickly pear (*raketa*), the silver wattle (*mimosa*), and, recently, the Asian common toad (*radaka boka*). Building on a conceptual approach to 'invasive species', this paper emphasizes the importance of inclusive and deliberative site- and population-specific management of invasive species. It analyses three separate concepts commonly used in definitions of invasion: the origin, behaviour, and effects of particular species. It places these concepts in their broader social and ecological context, with particular attention to local perspectives on invasive species. We illustrate these concepts with Malagasy examples and data. The examples demonstrate that while invasions can have dramatic consequences, there can be multiple, often competing, interests as well as site-specific biophysical, environmental, and cultural considerations that need to be taken into account when designing policy and management interventions. We conclude with a number of lessons learned.

RÉSUMÉ

Contrairement à la plupart des autres îles, et en dépit du qualificatif 'invasif' rattaché depuis longtemps à certaines espèces qui s'y sont naturalisées, les réflexions autour de l'approche des espèces invasives à Madagascar demeurent récentes. L'opuntia (*Opuntia* spp.) figure certes parmi les plus anciens exemples d'espèces traités dans la littérature sur les invasions biologiques. Mais ce n'est vraiment qu'avec le retentissement médiatique autour de la détection en 2011 de la présence du crapaud masqué (*Duttaphrynus melanostictus*) et la recherche d'une parade appropriée que s'est affirmée la nécessité de traiter cette question des espèces invasives en tant que telle.

Une posture nativiste et uniforme qui ignorerait la spécificité des contextes biophysiques et socio-économiques locaux, mais aussi la pluralité des formes d'invasion biologique et des définitions qui s'y rattachent, ne saurait être privilégiée. L'article montre qu'il s'agit de situer les réflexions dans un contexte insulaire socio-économique dans lequel les espèces allogènes tiennent depuis longtemps une large place. Il défend en outre la nécessité d'envisager les espèces invasives non pas selon une forme de perception unique et autoritariste, mais selon une diversité de points de vue, conforme aux conflits d'intérêts qui se manifestent parfois, et mettant plutôt en avant le caractère exogène des espèces invasives, leurs effets (négatifs, mais aussi positifs) sur le milieu, ou leur mode de fonctionnement (dispersion, dominance) dans des contextes spécifiques et locaux.

Il convient en particulier d'observer qu'aux coûts générés par les invasions biologiques peuvent s'ajouter des bénéfices économiques, et que les impacts écologiques néfastes peuvent se combiner avec des incidences heureuses, y compris auprès d'espèces indigènes en situation critique. En outre, le point de vue des populations humaines, leur connaissance d'espèces invasives quotidiennement rencontrées, leur réticence à scinder le vivant en espèces indigènes et allogène, mais aussi leur vision pragmatique, ne sauraient être mésestimés, et moins encore oubliés. Enfin, l'article invite à prendre du recul face aux effets rhétoriques liés aux discours conventionnels sur les invasions biologiques, à éviter les amalgames et les généralisations excessives, à tenir compte des contraintes environnementales mais aussi des aspirations socio-économiques des populations locales, et à prendre en compte la diversité des spécificités locales, qu'elles soient biophysiques ou sociales.

En conclusion, il est sans doute heureux que Madagascar n'ait rejoint que très récemment la mouvance internationale des réflexions sur les espèces invasives : cela lui permet en effet d'être en mesure de disposer d'une position équilibrée, déjouant certains discours catastrophistes, et préférant une approche résolument contextualisée, à l'échelle nationale comme aux échelles régionales.

INTRODUCTION

In 2011, the Asian common toad, *Duttaphrynus melanostictus* arrived in the port of the city of Toamasina and began to make

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its home in Malagasy soil. By early 2014, this species – which releases a toxin from its paratoid gland when stressed – had been spotted up to six kilometres from the port. Alarm bells were rung about the threat to biodiversity, amphibian diseases, water supplies, and domestic animal health from these "invasive venomous toads" (Kolby 2014, R. 2014). The spectre was raised of Australia's infamous experience with another bufonid, the cane toad[1] from the Americas, which has colonised much of northern Australia, affecting native biodiversity and becoming a nuisance for people (Seton and Bradley 2004). Yet calls in the high-profile journal Nature for rapid efforts to eradicate the Asian common toad in Madagascar led to a debate over the possible collateral damage of rapid eradication efforts, including the potential killing of native toads or the unforeseen consequence – or possible futility – of draining potential breeding ponds (Andreone 2014, Mecke 2014).

Such debates are hardly new: nearly one hundred years ago, the control of an invasive variety of *Opuntia* (prickly pear cactus, raketa) in the south of Madagascar through the release of a scale insect[2] met with vehement protest, given the plant's utility as a famine food (Middleton 1999, Kaufmann 2001, Binggeli 2003a). Yet, such debates over invasive species are relatively rare in Madagascar. The topic has received "scant attention in recent decades" and "little is known about the distribution or impact of any introduced species" (Binggeli 2003b: 257). In comparison with elsewhere, conservation decision-makers and actors in Madagascar have tended not to focus on invasive species, not seeing them as a major issue (Carrière et al. 2008). Invasions were not addressed, for instance, at the 2006 Conservation International biodiversity symposium held in Madagascar (ibid.). The first event to focus on invasive species on the island was only held at the University of Antananarivo on 9–10 October 2013.

The above context, together with the recognition that there are indeed a fair number of invasive species on the island (Binggeli 2003b; Kull et al. 2012), suggests that it is important to consider how one should approach the question of invasive species in Madagascar. With the continuously growing volume and speed of human movements and trade in recent years, chances increase for further introductions of non-native plants and animals. It can be tempting to adopt a hardline nativist posture that rallies resources to fight invasions perceived at first glance to be uniform threats to the economy or to biodiversity. However, as the debates over the cane toad and prickly pear hint, there are multiple, often competing, interests as well as site-specific biophysical, environmental, and cultural considerations to take into account. Even the terminology and definitions of 'invasion' can be confusing. In order to highlight and address these complexities, this paper approaches the issue of invasive species in Madagascar from a conceptual point of view. It dissects the concept of invasion, illustrates it with Malagasy examples and data, and provides some recommendations for policy and practice. Our analysis suggests that it is important to avoid categorical approaches, and emphasizes instead the importance of a deliberative site- and population-specific approach.

BACKGROUND: A MELTING POT ISLAND

Madagascar, a large island of highly endemic flora and fauna and relatively recent human settlement, nonetheless hosts numerous life forms familiar around the tropics and subtropics. For instance, to choose one landscape, a visitor from southern India, Mozambique, or Fiji would not feel too out of place in eastern Madagascar. There, the mix of cultivated and spontaneous plants and animals is a Malagasy version of the typical cosmopolitan humid tropical smallholder landscape. The fallow hillsides and field and path edges are made of a number of species, both native and introduced, some of which are rapid colonizers of open terrain. Common species include *Rubus alceifolius* (Moluccan bramble), *Clidemia hirta* (Koster's curse), *Ravenala madagascariensis* (traveller's palm), Pteridophytes (ferns), *Aframomum angustifolium* (wild ginger), *Bambusa* spp. (bamboo), *Eucalyptus*, *Pinus* spp. (pines), *Psiadia altissima* (dingadingana), *Lantana camara*, *Psidium cattleianum* (strawberry guava), *Albizia* spp., *Grevillea* spp., and nevermind domestic and commensal animals like *Bos indicus* (cattle), *Canis lupus* (dogs), and *Rattus rattus* (rats). Like elsewhere around the world, humans have introduced a wide variety of plants and animals over the past millennia for diverse reasons: food, economic aspirations, aesthetics, or accidentally.

The study of non-native species and weeds on the island arguably began with the indefatigable Perrier de la Bâthie's publication of *Les pestes végétales à Madagascar* (1928) and *Les plantes introduites à Madagascar* (1931–32) and the management issues regarding prickly pears and lantana in which he became embroiled (Middleton 1999, Kaufmann 2001, Binggeli 2003a, c). Aside from agronomic and forestry work on introducing new cultivars and on fighting common nuisance plants, little attention was given to 'invasives' as a category until Pierre Binggeli's contributions to the tome Natural History of Madagascar. Binggeli's (2003b) main chapter provides a landmark overview of the island's invasive plant species, but laments that the "dearth of quantitative data and information prevents the production of a comprehensive review" (Binggeli 2003b: 257). He lists 38 species of flowering plants as invasive in Madagascar, or at least present on the island and known to be invasive elsewhere. He highlights the historical stories and ecosystem effects of nine species in detail, six in the main chapter (*Clidemia hirta*, *Cissus quadrangularis*, *Psidium cattleianum*, *Rubus alceifolius*, *Rubus rosifolius*, and *Solanum auriculatum*) three others in separate chapters (Binggeli 2003a, c, d): *Opuntia*, *Lantana camara*, and *Eichhornia crassipes* (water hyacinth). More recently, a biological conservation textbook adapted for a Malagasy audience devotes five pages to invasive species (Primack and Ratsirarson 2005), and in 2012 we built on the work of Perrier de la Bâthie and Binggeli to establish an extensive inventory of plant species introduced to the island. In this inventory we noted whether species had displayed invasive behaviour (Kull et al. 2012).

WHAT ARE 'INVASIVE' SPECIES?

In discussing invasive species, it quickly becomes apparent that the concept is open to interpretation. First of all, while the term is applied to species, it is of course never a species that is invasive, but particular populations of some species in particular habitats or ecological conditions (Colautti and MacIsaac 2004). Conversely, species that are invaders in one place may in turn be threatened in their native habitat. Second, it has been amply shown that the language of invasion and its reliance on military or nationalistic metaphors predisposes

people to think in certain ways about those life forms labelled invasive (Tassin and Kull 2012). Third, and most importantly for this paper, even the scientific definitions of 'invasive species' differ strongly in their emphases (Colautti and MacIsaac 2004, Tassin 2014). In this section we review the concept of invasion at a general theoretical level; in the sections that follow we apply each of the key themes raised here (origin, behaviour, effects, and local perspectives) to invasive species in Madagascar.

There are three main axes in definitions of invasive species that get emphasized, suppressed, or elided depending on the point of view and goals of the person using the term (Larson 2007). These are the 'effects' (and our judgement of those effects), the 'origin' (where a species is thought to come from), and the 'behaviour' (the act of rapid spread and domination) of the particular population of 'invasive' species. These correspond with the terms often used in such cases, like alien, invasive, weed (or pest for animals and insects). Particular definitions emphasize one or the other axis, or two, or uncritically mix bits of all three.

The focus on 'effects' is probably the oldest axis in the concept of invasive species, for the concepts of weeds and pests existed long before the science of invasion biology. Research of a more applied perspective tends to favour definitions of invasive species that emphasize this aspect – a negative impact such as threats to indigenous biodiversity, or quantifiable economic costs (McNeely 2001, Simberloff et al. 2013). People will of course always judge plants and animals and the consequences of their introduction or proliferation; opinions, thinking, and judgement are part of being human. These judgements will of course vary with peoples' interests, prevalent ideas, and the current economic situation. For instance, the judgement of impact may be coloured by the native or non-native status of a species, with effects judged negatively just because a species is 'alien' (or, conversely, romanticized because it is 'exotic'). Moreover, consensus can be misleading, because it reflects a dominant, sometimes hegemonic, way of thinking.

Other definitions of invasive species specifically break with the question of impact. Richardson et al. (2000: 93) suggest "that the term 'invasive' should be used without any inference to environmental or economic impact", noting that terms like 'pests' and 'weeds' are suitable labels for those cases. Richardson et al. go on to define invasive species as, essentially, those that are alien (those which owe their presence in a given area to purposeful or accidental human introduction), naturalized (those which reproduce consistently without human intervention), and in addition those that have the potential to spread over a considerable area and at a high speed. The underlying narrative could be said to be that when humans take species beyond their natural ranges and they reproduce abundantly, the rules of the game are broken. This is a dual focus on origins and behaviour, but with the additional layer of human agency. The work of Richardson and colleagues strongly emphasizes biogeographic themes like native distributions and dispersal barriers (mountains, climate bands, or oceans). Their focus on human agency in moving species across such barriers is on the one hand practically quite relevant (humans move many species, quite frequently, and in great numbers; our actions can in principle be managed through policy) but also conceptually problematic as it reifies a divide between nature and culture (Frawley and McCalman 2014).

A strict focus on origins, where non-native status is linked to the concept of invasive species, has several issues (Warren 2007, Davis et al. 2011). For one, the concept of 'nativeness' is spatially and temporally relative, in the sense that species ranges are not fixed but 'naturally' shift over space and time (Webber and Scott 2012). Second, nativeness is also scale sensitive: a species can be native to Madagascar, but only to certain regions of the island, and can also have been introduced from one region to another one. We do not know the current range, the pre-human range, nor the range at last glacial maximum (for instance) for most Malagasy species, which complicates such discussion. For convenience, in online databases, floras, and species lists, native status is often reported using administrative or geopolitical entities, which can lead to awkward policy conundrums, as when a garden shop sells a 'native plant' that is actually only native to a distant corner of the same country (Head and Muir 2004). In Madagascar, for instance, the native species *Delonix regia* (flamboyant) and *Terminalia mantaly* are originally restricted to the south, but have been planted as ornamentals around the island (and across the tropics in general). Third, sometimes there are problematic associations made between species origins and national identity, both in terms of nationalism about natives and fear of the alien (Comaroff and Comaroff 2001, Tassin and Kull 2012, Mastnak et al. 2014). Finally, invasive behaviour is not limited to non-native species (Valéry et al. 2009). We turn to this theme now.

'Behaviour', or the act of rapid spread and dominance in particular ecological contexts, is probably the part of the invasive species concept most closely related to the dictionary meaning of the word 'invasive' in the sense of "intruding on the domain of another". Davis (2009) has promoted an approach to invasion biology re-centred on 'species redistribution' and the means by which some species expand or contract in different ecological contexts. Along these lines, Valéry et al. (2008: 1349) define invasion to be when a species acquires "a competitive advantage following the disappearance of natural obstacles to its proliferation, which allows it to spread rapidly and to conquer novel areas within recipient ecosystems in which it becomes a dominant population". One must of course be careful not to separate this behaviour from the human driving actions (land use, pollution, climate change, as well as transport) that lie hidden and unexplored behind these processes (Tassin 2014).

The above concepts, in varying combinations, have been used to produce official and scientific knowledge about a category – 'invasive species' – that was invented some fifty years ago (Richardson 2010). It is important to realize, however, that these formal representations, which carry the power of science and result in categories, lists, and policies used by government agencies, jostle up against different forms of knowledge and understanding, including practical everyday tactile and emotional experiences and indigenous or alternative local perspectives (Kull and Rangan In press). Different people have different approaches to the plants and animals they encounter in their fields, gardens, yards, and streets, sometimes reflecting dominant scientific ideas, and sometimes running counter to them. Paying attention to these 'local perspectives' both helps to critically reflect on 'official' categories and to find more pragmatic, contextual, and just management approaches (Bentley et al. 2005, Trigger 2008).

In the next four sections, we apply each of these ways of defining invasive species – origin, behaviour, effects, and local perspectives – to the case of Madagascar.

ORIGIN: NATIVE OR NOT NATIVE TO MADAGASCAR?

The Indian Ocean forms a clear biogeographical barrier around Madagascar, at least for terrestrial species. Species have periodically crossed this barrier, including lemurs and chameleons (Dewar and Richard 2012, Tolley et al. 2013). Human travel and trade over the last two, perhaps four, millennia undoubtedly increased the frequency and magnitude of introductions. While the exact nature and timing of prehistoric migrations and trade links between Madagascar, nearby coastal Africa, the Indian Ocean rim, and the distant homeland of Austronesian settlers remains contested (Beaujard 2011, Dewar 2014), ample opportunities existed for transfers, and these transfers enabled society to flourish on the island but also introduced certain 'alien' weeds and pests. European and colonial contacts, and modern agronomic and forestry interventions, and global trade increased the possibilities for new species to arrive (Kull et al. 2012).

Madagascar hosts 50 or 60 introduced animal species and around 1,200 introduced vascular plant species. We documented elsewhere (Kull et al. 2012) that the absolute number of introduced plant species is small when compared to other island groups (the other islands are typically wealthier places with more trade in ornamentals). The relative number of introduced species (ca. 1,200) compared to the native flora (at least 11,220: Callmander et al. 2011) is also small, more typical of continents, in part due to the large number of native species. However, the percentage of introduced plant species that has been labelled 'invasive' (following any definition) is relatively high, at 8.9 per cent. This likely reflects the fact that while the introduced flora is relatively small, it includes many common weedy plants but fewer specialized ornamentals.

While being an island should make it relatively easy to distinguish native from alien, the antiquity and ubiquity of human and non-human dispersal of species means that many species are cryptogenic. We found 174 plant species on Madagascar with uncertain status (Kull et al. 2012). Furthermore, within the island's borders, researchers have identified biogeographic barriers or distinct native distribution zones that could be used to label plants or animals as non-native in other parts of the island (Wilmé et al. 2012, Ganzhorn et al. 2014). These distinctions can be difficult to identify (surveys are not always comprehensive) and to use as a basis for management (if a species is found near, but outside its supposed native range, what should one do, particularly in a context of climate change?). Finally, species native to Madagascar have also shown invasive tendencies on the island, for instance *Cynanchum* vines in Beza Mahafaly Special Reserve (Sussman and Rakotozafy 1994, Ratsirarson 2005).

In sum, on the one hand, a singular focus on origins in approaching invasives is problematic. While many of the prominent invasive species in Madagascar discussed below in terms of behaviour or impact are alien, some are not alien, some are cryptogenic, and some arrived by themselves. Non-native species can be invaders, but they can also form fundamental pillars of the country's economy and culture, as do rice, vanilla, cloves, eucalyptus and zebu. On the other hand, given that many (though not all) problematic species are those that are introduced from far away, a focus on origins suggests a key intervention strategy for mitigating future invasions: phytosanitary control. The borders of an island nation like Madagascar are the one place where it is practically and institutionally possible, though difficult, to screen the entry of new alien species. Such care may have avoided the introductions of species widely considered problematic elsewhere, such as *Acridotheres tristis* (the common myna), a cosmopolitan commensal bird.[3] It has now spread across many of the anthropogenic landscapes of the island, arriving in Antananarivo a decade ago (Primack and Ratsirarson 2005).

BEHAVIOUR: SPREADING AND DOMINANCE IN DISTURBED HABITAT

Plants and animals that spread rapidly and gain dominance – often in environments made 'invasible' through human interventions like ploughing, deforestation, fertilization, irrigation, fire control, or other modifications to existing soil or vegetation, or indeed through natural forest blowdowns from cyclones (Alpert et al. 2000) – are numerous on the island (Perrier de la Bâthie 1928, 1931–1932; Binggeli 2003b). Such invasive behaviour occurs at several scales. At the spatial and temporal scale of an annual cropfield, examples include diverse herbaceous adventive plants, both native and introduced, such as *Bidens pilosa, Heteropogon contortus*, and *Leersia hexandra* (Husson et al. 2010); in a slash-and-burn plot the dominant species are initially grasses and then other pioneers like *Harungana madagascariensis* (Randriamalala et al. 2014). At the scale of a small protected area and a particular management intervention (the exclusion of cattle grazing from a 100 ha parcel), one might mention the rapid spread of *Cynanchum* vines into the forest canopy at Beza Mahafaly Special Reserve (Sussman and Rakotozafy 1994, Ratsirarson 2005). At a regional and decadal scale, examples of invasive behaviour include the spread of *Lantana camara* to cover 100,000 ha in the Mangoro valley a century ago (Binggeli 2003c), the ubiquity of silver wattle in parts of highlands (Kull et al. 2007), the development of monotypic stands of *Ziziphus jujuba* (jujube) in the 1970s near Ankarafantsika in the northwest, the recent explosion of *Grevillea banksii* in many sections of the eastern lowlands, the spread of *Acridotheres tristis* across the island, and – potentially – the spread of *Duttaphrynus melanostictus,* the toad mentioned in the introduction.

The above examples hint at an important point: often there is a temporal aspect to invasive behaviour. Invasive plants are often heliophilous pioneers, some of which have relatively short life spans and which, without further disturbance, are complemented or replaced by other species. For instance, the spread of non-native 'invaders' like *Cecropia*, *Musanga* and *Clidemia hirta* in disturbed tropical rainforest is akin to the behaviour of early successional species and they are likely to be replaced by more shade tolerant native forest trees over time (Holland and Olson 1989, Whitmore 1990, Rakotonirina et al. 2007). In other cases, the impact of logging and subsequent invasion appears to last much longer, even centuries (Brown and Gurevitch 2004). For both plants and animals, their evolutionary and competitive advantages eventually decline as local predators and pathogens adapt to the new opportunity. For instance, *Lantana*

invasions in several tropical islands – such as New Caledonia (Tassin 2014), Timor (McWilliam 2000) – at first spread quickly and then subsided, which may be the case in Madagascar, given the alarm with which Perrier de la Bâthie viewed 100,000 ha invaded eighty years ago (Binggeli 2003c) and its widespread but not particularly invasive state today.

Environmental managers sometimes rely on the capacity for certain species to spread rapidly and become dominant to achieve certain goals, most commonly for protection or restoration of degraded lands. Two small trees (*Acacia dealbata* and *Grevillea banksii*) whose seeds were widely dispersed in the Lake Alaotra region for erosion control and 'regreening' because of their colonizing ability were actually widely considered to be failures, for they did not establish themselves nor become dominant (Tassin 1995). This is in sharp contrast to their spread in other more suitable regions, as we note elsewhere.

Interestingly, Perrier de la Bâthie's (1931–1932) seminal review of the island's introduced plants classified species based on their behaviour and the kinds of disturbed areas they were found in. His categories included cultivated plants (i.e., no invasive behaviour), and three groupings of pioneer and light-demanding species: *plantes adventices* (essentially, weeds), *rudérales* (growing around houses and waste heaps), and *messicoles* (growing in fields, along paths, road verges). Perrier de la Bâthie also listed 72 native or endemic plants that have become ruderal or messicole, emphasizing the incompatibility of the category 'behaviour' with that of 'origins'. More recently, a team of agronomists has prepared a guide to the fallow field plants and crop weeds (*adventices des cultures*) of Madagascar (Husson et al. 2010), using plant behaviour (colonization) in particular habitats (crop fields and fallows) as the overall criteria for inclusion.

EFFECTS: NEGATIVE AND POSITIVE OUTCOMES

When speaking about the effects of invasive species, the focus tends to be on economic burdens (such as reduced agricultural harvests or increased management budgets) or impacts on biodiversity (such as threatening native species or transforming habitats). It is important, however, to remember that effects can be both positive and negative, and that the determination of whether effects are good or bad always incorporates an element of human judgement (Tassin and Kull 2015). Here we provide examples of a number of different types of effects on Madagascar.

ECONOMIC COSTS. Crop field weeds, both native and introduced, reduce agricultural productivity by competing with crops and by necessitating costly labour or chemical treatments (which in turn may lead to pollution or toxic health effects). Husson et al. (2010) review the principle weed plants from an agronomic perspective, and catalogue the types of manual or herbicide control found to be most effective. The *Eichhornia crassipes* (water hyacinth) clogs many lakes and waterways including the Pangalanes Canal and Lake Alaotra, as well as rice fields. The city of Antananarivo expends considerable effort in removing it annually from Lake Anosy (Binggeli 2003d). As far as animals go, we might highlight the impact of *Rattus rattus* (black rats), which arrived with early humans and spread in disturbed habitats around the island associated with human settlements, and which have serious consequences in terms of spreading diseases, threatening food stocks, and even eating rice in the rice fields (Lehtonen et al. 2001, Tollenaere et al. 2010). Likewise, the recent spread of *Procambarus* 'Marmorkrebs' (marbled crayfish) in rivers close to Antananarivo is thought to threaten rice production (Jones et al. 2009, Kawai et al. 2009).

ECONOMIC BENEFITS. Villagers take advantage of a diverse number of invasive plants for their livelihoods, making the most of what they find in their landscapes. Lehavana (2012) lists *Opuntia, Grevillea, Psidium cattleianum, Oreochromis niloticus,* and *Rubus alceifolius* as species appreciated as food, wood, or otherwise; one could also add to this list *Pinus* for construction wood, *Ziziphus jujuba* for charcoal and fruits, and so on. The use of invasive *Opuntia* species in the south as cattle fodder and as hedges has been widely documented (Binggeli 2003a, Kaufmann 2004, Kaufmann and Tsirahamba 2006, Middleton 2012). The spread of *Acacia dealbata* (silver wattle or *mimosa*) across the highlands contributes fuelwood, charcoal, minor construction wood, and soil fertility and is broadly appreciated (Kull et al. 2007, Tassin et al. 2012). Even *Eichhornia crassipes*, the water hyacinth, has found some use as pig food and in artisanal basket weaving (Rakotomalala 2014).

It is not just villagers who benefit economically from some invasive species. The trade in charcoal and other wood products from invasive wattles, grevillea, and pines, in different regions of the island, feed important commodity chains into the main cities. On a different note, in Ranomafana National Park, key tourist sites are invaded by the *Psidium cattleianum* and according to park managers these sites help ensure a 100 percent success rate in finding lemurs to show to tourists, ensuring the economic success of the park (Carrière et al. 2008). Of course, this fruit bearing species is also highly appreciated by villagers for diverse uses and marketable products – food, jam, alcohol. Villagers also practice slash-and-burn farming in land rendered more fertile by diverse invaders, including *Psidium* (Carrière et al. 2008).

ECOLOGICAL COSTS. Diverse negative ecological impacts have been noted. As in other contexts, the presence of feral or invasive predatory animals appears to have more stark consequences than that of plants. The introduced fish known locally as *fibata* (snakehead, *Channa maculata*), brought to the island through President Ratsiraka's enthusiasm for aquaculture, is now found in most lakes around the island (Masuda et al. 1984, Sparks and Stiassny 2003). At Lake Alaotra, collection of this fish is one of the reasons villagers burn marshlands that are crucial habitat of the gentle lemur (*Hapalemur alaotrensis*) (Copsey et al. 2009). It has been widely suggested that the fish may be responsible for the local extinction of the fish genus *Paratilapia* and the total loss of the Alaotra grebe (*Tachybaptus rufolavatus*), but causality has not been scientifically proven. A landmark early assessment of Madagascar's freshwater fishes paints a stark picture of the likely impact of diverse introduced fish on native species. It found almost no native fish species in some inland lakes and waterways stocked with introduced fish (Reinthal and Stiassny 1991, see also Lévêque 1997, Sparks and Stiassny 2003 and Irwin et al. 2010). On the mammal front, feral cats have been shown to predate on sifaka (*Propithecus verreauxi*) at Beza Mahafaly Special Reserve (Brockman et al. 2008), while feral dogs have reduced fosa (*Cryptoprocta ferox*) populations in Ankarafantsika National Park (Barcala 2009). While rats are widely known

the world over to have devastating impacts on native fauna, and such impacts are imputed for Madagascar (Hingston et al. 2005), Ganzhorn (2003) demonstrates for one case study in the Menabe that there is no indication of negative interactions between rats and native small mammals. As far as insects, Irwin et al. (2010) remind readers that at Tampolo forest in the east, the presence of white-footed ant (*Technomyrmex albipes*) in disturbed, fragmented forest is associated with reduced native ant populations.

As far as plants, some examples suffice. Thick carpets of *Eichhornia crassipes* are detrimental to a native duck species (*Thalassornis leuconotus*) at Alaotra (Binggeli 2003d). Pines (*Pinus*) spreading into tapia (*Uapaca bojeri*) woodlands or montane park areas like Andringitra or Ibity may have allelopathic effects on the soil (Bosshard and Mermod 1996). The large African vine *Cissus quadrangularis* smothers trees and apparently prevents regeneration in degraded gallery forests of the far south, such as Berenty (Binggeli 2003b). The invasion of logged forests by plants such as *Psidium cattleianum*, *Eucalyptus robusta*, and *Syzygium jambos* is suggested to prevent regeneration of native forest species and result in lower species richness (Brown and Gurevitch 2004).

Species like *Leucaena leucocephala* have been labelled in the literature as "transformer species", because they "change the character, condition, form or nature of ecosystems over a substantial area" (Richardson et al. 2000: 98). This particular species from the Americas is known to form monotypic stands in diverse places where it has been introduced (e.g., Australia, New Caledonia, Fiji). In Madagascar, it has been studied in detail at Orangea forest (near Antsiranana), where it was labelled a conflict of interest due to its transformation of local vegetation communities at the same time as its beneficial uses by local people and livestock (Raharinaivo 2013). At the other end of the island, *Leucaena* is known to have caused 'bald lemur syndrome' in groups of *Lemur catta* that fed on it (Jolly 2009).

ECOLOGICAL BENEFITS. Invasive species may have positive impacts on ecological processes as diverse as soil erosion, habitat provision, or forest regeneration. Foresters have encouraged the invasions of *Pinus*, *Grevillea*, and other species into *lavaka* erosion gullies and other degraded land in order to stabilize the soils (Tassin 1995, Carrière and Randriambanona 2007). *Acacia dealbata* in the highlands, and *Grevillea banksii* in the eastern coastal region, have been considered positively by many policy makers and foresters for 're-greening' and adding tree cover to a landscape perceived to be degraded (Kull et al. 2007). Indeed, both were considered for aerial distribution of seeds by foresters.[4]

Some native species are opportunistic and feed on invasive species or use them as habitat. In some cases, this may positively affect the native species (Tassin and Kull 2015), though further research is warranted. For instance, lantana flowers are a favourite food of an endemic butterfly (*Hypolimnas dexithea*) at Montagne d'Ambre (Binggeli 2003c). Native lemurs, bats, and birds feed on a number of introduced species (Gérard et al. In lit.). As one example, white collared brown lemurs (*Eulemur cinereiceps*) in Manombo forest were shown to rely on introduced plants often considered invasive (*Cecropia peltata*, *Aframomum angustifolium*) as 'fallback' food opportunities in habitat disturbed by a cyclone (Ralainasolo et al. 2008). Finally, afforested zones of *Eucalyptus*, *Pinus*, and *Acacia* – the latter two sometimes invasive – in the eastern highlands play a role in attracting seed dispersers and helping to regenerate native forest vegetation in former pastures (Randriambanona 2008).

LOCAL PERSPECTIVES

What does the Malagasy public think about 'invasive species', and what can their perspective contribute to science and policy? Like anywhere, peoples' views will vary based on the nature of their daily lives, location, and occupations, and their exposure and familiarity with local, foreign, and scientific ideas about the environment and terms such as 'invasives' and 'weeds'. Based on some preliminary fieldwork in a few rural areas[5], we can suggest a number of important observations.

1. Awareness: Farmers, as well as conservation agents, are (unsurprisingly) quite aware of new and/or rapidly-spreading plants or animals in their crop fields or broader environs. When asked, they could quickly point to something new that they had not seen before, or mention a plant or animal that was problematic for their farming activities. We were shown four new plants in cropfields in four different sites; all had only been observed for a season or two in the memory of the farmers who showed them to us. Likewise, people in the eastern lowlands were quite aware of the rapid expansion of *Grevillea*.

2. An engagement with particular plant species, more than with categories like 'invasive' or 'exotic': At a local scale, broad categories like 'invasive species' or 'exotic species' are much less useful in discussions than names or examples of specific plants or animals. Indeed, terms like invasive species do not exist in the Malagasy language. There is a Malagasy word that translates closer to the French *mauvaises herbes* than the English 'weed': *ahidratsy* or literally 'bad grass'. Farmers appear to have a rather specific, narrow use of this word – restricted to plants in cropfields that reduce the harvest, compete with the crop; it does not include fallow plants. This is confirmed and even narrowed further by a dictionary definition as "a grass growing with rice that requires weeding" (Rajemisa-Raolison 2003). Our discussions with farmers went much further when we spoke about the character, advantages, and disadvantages of particular species in specific contexts, rather than when we used abstract generalities.

3. Withholding judgment and searching for utility: The term *ahidratsy*, as mentioned above, contains the judgment *ratsy* (bad) within it. Farmers were generally quite hesitant to label new, unknown plants *ahidratsy*. This is not due to ignorance. Instead, farmers told us "no, this plant is not an *ahidratsy*" for various reasons – for the plant was useful, for it was not a weed of crop fields, or because the farmer did not know yet whether the plant was damaging or useful. For instance, in two villages east of Lake Alaotra, people mentioned the arrival of a new plant that they did not know. They showed the plant to us – it had a spiny thistle-like shape, producing thousands of seeds. It grew prolifically across several fields of market vegetable crops (tomato, cucumber, Chinese cabbage), with both mature plants and numerous seedlings. Despite its obvious weedy aspects, the farmers refused to call it *ahidratsy*, as they did not yet know what it was nor its potential uses. The plant in question in this case was *Argemone mexicana* (Mexican poppy), which is a common alien weed in southwestern Madagascar and was already sold as a medicinal plant in the outdoor market in Antananarivo over twenty years ago (Boiteau and Allorge-Boiteau 1993, Husson et

al. 2010).[6] In general, curious farmers rapidly adopt new plants for their diverse utilities. For instance, *Senna occidentalis* was introduced to the Alaotra area in the 1950s, and soon became part of the local pharmacopeia of medicinal plants.

4. Origin unimportant: Villagers were largely either unaware of or unconcerned with a plant's origins, as is the case in many parts of the world. While experiences might be different in other places, or with well-known species, in our experience on this set of field visits the topic of whether a plant was native or alien never came up as a topic with villagers unless we specifically asked about it. In no case was origin linked to impact or behaviour. Indeed, people generally looked perplexed when we asked whether a species was "*gasy na vahiny?*" (Malagasy or visitors?). When asked this question directly regarding introduced plants like *Lantana* or *Grevillea*, most people responded without hesitation that they were *gasy*.[7] A few conversations were more nuanced, with one farmer suggesting that if a plant had a name in the Malagasy language, it was probably from Madagascar, and if it did not, that it was brought more recently. He compared *Lantana* (*radriaka*) which he presumes (erroneously) was Malagasy with *Albizia* (*albiza*) which he correctly identified as introduced. It should, however, be noted that the Malagasy language does label a number of plant varieties with epithets (like *vazaha*) that may indicate origin, like *angivy* (*Solanum erythracanthum*, a native nightshade family plant) versus *angivimbazaha* (cultivated eggplant), or *dingadingana* (native *Psiadia altissima*) versus *dingadingambazaha* (non-native *Justicia gendarussa*).[8]

LESSONS FOR APPROACHING INVASIVE SPECIES IN MADAGASCAR

Despite being considered in the recent past by many conservation actors and policy makers to not be much of an issue (Carrière et al. 2008), recent reviews cite invasive species as major threats to Madagascar's biodiversity (Irwin et al. 2010, Rakotomanana et al. 2013). The latter article, for instance, mentions the possible arrival in Madagascar of the chytrid fungus *Batrachochytrium dendrobatidis*, which has had terrible impacts on its amphibian hosts in many regions throughout the world. So, given these concerns, what should we do about invasive species in Madagascar? Our review – based on the insights from dividing the issue into several conceptual categories (origins, behaviour, and effects, as well as local perspectives) – suggests a number of lessons that may guide research, policy, and management.

1. 'Invasive' is often an imprecise term used for rhetorical effect: The term is used by different people, following different definitions that group different processes (such as crossing biogeographic boundaries with anthropogenic help, or spreading quickly on its own) and different judgments (about origins, or about impact). The term often sticks to a species, when it is more appropriately applied to particular populations of a species in particular contexts. The term can also distract attention from the human uses of the environment that render certain sites invasible, focusing the blame on species rather than the human context. So care is advised in using the term; we should strive to be more specific in describing the phenomena we observe.

2. To be more specific, we should be clear about origins, behaviour, and effects, and distinguish between rather different categories like plants, predators, and pathogens. We might follow the lead of the local people, whose discussions are very site- and species-specific: Madagascar hosts over a thousand alien species, but only a subset have spread quickly or become problematic. Some populations of particular species, whether alien or native, spread quickly and become dominant when given the opportunity. This behaviour occurs at different spatial and temporal scales. Different species populations have different effects, both positive and negative, and some can be qualified as noxious weeds or pests. Being more specific helps us know what we are talking about. For instance, when Amsellem et al. (2000) state that the non-native bramble *Rubus alceifolius* is not especially invasive on Madagascar, compared to elsewhere, it is unclear whether 'invasive' refers to spreading behaviour or negative impact, or both. Being specific also brings to the forefront what aspects are important for management: is it about border control of new alien pathogen arrivals, is it about managing land better to make it less invasible by a transformer species, or is it about seeking to mitigate negative impacts on crop production of a particular pest?

3. Many plants and animal populations labeled 'invasive' have positive as well as negative aspects: This is shown by local peoples' resourcefulness in making use of *Argemone mexicana*, *Acacia*, *Grevillea*, *Melaleuca*, and *Potamochoerus larvatus*, just to name a few, or by the opportunistic use by some native fauna of *Psidium*, *Eucalyptus, Lantana* and other introduced and sometimes invasive plants as food or habitat.

4. The mix of positive and negative impacts, and the location of invasions in lands and waters of livelihood and cultural importance to local people, means that social justice and economic development should be considered alongside ecological conservation: The process of decision-making and management should be as inclusive as possible. To paraphrase Forsyth and Sikor's (2013: 120) discussion of justice in the management of forests, the management of invasives "is a process that never becomes perfect (…). The process of discussion, where social inclusion itself is critically sought and predefined norms are not imposed, might lead to a more just outcome because it acknowledges that the definition of benefits is influenced by social inclusion and that facts and norms influence each other." Such deliberative management is necessary, for "human desires for preserving certain social values in landscapes in contradiction to actual transformations is often at the heart of definitions of and conflicts over weeds or invasives" (Kull and Rangan In press).

5. Different management strategies and approaches for invasives are applicable to different sites and social contexts: First of all, there is the option, in some cases, of direct interventions on populations of weeds, pests, and other 'invasives' that farmers, environmental managers, or others decide to eradicate (if feasible) or at least to control. This usually requires serious investments. Labour for cutting, catching, or killing is frequently arduous or expensive. Chemical control is possible – see for instance the work of Miandrimanana et al. (2014) on invasive *Melaleuca quinquenervia* (*niaouli* or paperbark) in Analalava – but it can have deleterious toxic effects on ecosystems and people. Biocontrol research to identify appropriate biocontrol agents, to test them for host specificity, and to release them is expensive and prone to unexpected effects, as shown by the spread of crop-thieving *Acridotheres tristis* introduced to

control locusts,[9] or the colonial era debates over the release of scale insects to control *Opuntia* mentioned earlier.

A second set of strategies focuses not on the invaders themselves, but on the environments which they invade. As our earlier discussions suggest, in many cases invasive behaviour is shaped by the environmental context. Human changes to the environment – ploughing, fertilization, irrigation, deforestation, removal of predators, changes to fire regimes – can open opportunities that certain plants and animals exploit. There is evidence from Ranomafana National Park, for instance, that protected areas, by stopping habitat fragmentation and anthropogenic disturbance, reduce the presence and opportunity for spread of common invasive species (Brown et al. 2009). Agronomists have long looked at ways to reduce weed growth that involve not just herbicides, but also different ploughing and fertilizing strategies. So, depending on the context, interventions on invasions may need to focus on land or marine management rather than the invaders themselves.

A third kind of intervention arises from the 'origins' concept. As noted earlier, an important lever for controlling future invasions is blocking entry to the island of those non-native species that society deems (in an informed, deliberative process) might carry risks above a certain threshold. Several other governments take a precautionary approach at their borders, seeking to screen new arrivals of species for potential problems. For instance, Australia has established a strong biosecurity quarantine service at sea- and airports, and uses decision tools that weigh benefits and risks of potential new pests and pathogens based on experience elsewhere (Kumschick and Richardson 2013). One might add that given the importance of propagule pressure in leading to invasions, internal policies might be used to discourage the anthropogenic diffusion of problematic plants and animals already present on the island.

Fourth, another strategy worth exploring in many cases is compromise or even "living with" invasive species (Head et al. In lit.). The financial and human resources to cope with biological invasions that are already widespread are limited. Pragmatic approaches should be locally relevant, socially appropriate, and result from prioritization exercises. In many cases, this might mean doing nothing, or managing particular important sites (for farmers, for local cultural reasons, for biodiversity), rather than waging blanket wars against particular species. In some ways, it is fortunate that Madagascar has come to focus on biological invasions rather late compared to other regions, for it allows researchers and managers to apply a more mature, balanced approach, than the categorical, catastrophist alarm that is sometimes raised. In many cases, plants and animal seen as invasive are – in practical, non-idealistic terms – important opportunities for rural economic, social, and ecological sustainability. They give people subsistence and livelihood alternatives, particularly when access to native forests is restricted by conservation policies (Carrière et al. 2008), and they can serve as important components in resilient smallholder farming landscapes (Kull et al. 2013).

In conclusion, our review has shown the importance of a deliberative approach specific to particular sites, species, and categories of invasion. The capacity for certain populations of plants and animals to spread rapidly, transform landscapes, and become a nuisance to humans or wildlife is certainly worthy of concern and action. However, each case will have its social and ecological particularities, and a blanket approach is not feasible, not realistic, nor likely to be fair to the people living their daily lives in these landscapes. Researchers can contribute carefully-acquired knowledge about different invasions and their contexts; managers and policymakers must use the information available to them, and in inclusive deliberations with local people and other interested groups decided on the most appropriate plans for action. On this note, to return to our opening example of the common Asian toad in Toamasina, we send our best wishes to the teams working with local communities to assess the risks and identify feasible and appropriate management options at this early stage in the invasion.

ACKNOWLEDGMENTS

We thank the editors of MCD for their invitation to pen this article, the reviewers for their comments, and Herizo Razafimampanana for fieldwork assistance. CK's research was funded by the Australian Research Council (DP130103341).

NOTES

[1] The cane toad is *Rhinella marina* (previously *Bufo marinus*).

[2] The scale insect was *Dactylopius*, of the same genus as the carmine-producing cochineal.

[3] Newton (1863: 349) saw the bird at Fenerive and Foulepoint in the 19th century.

[4] Gabrielle Rajoelison, ESSA-Forêts, pers. comm., July 10, 2014.

[5] Based on scoping field trip by CK with Herizo Tantely Razafimampanana in July 2014 consisting of discussions and terrain walks with villagers in two sites in the central highlands, two sites near Lake Alaotra, one site near Beforona, and three sites near Vatomandry.

[6] *Argemona mexicana* is probably not all that new to the region; one of us (JT) suspects having seen it in the Alaotra area in the early 1990s.

[7] SC (pers. observ.) had different experiences in earlier interviews about eucalypts, where younger generations considered the plants to be 'gasy' but old people recognized them as introduced.

[8] For a more detailed discussion of plants labeled 'gasy', 'vazaha', and 'manga', see Kull et al. (In press). Several of the numerous plants and seeds available from the Silo National des Graines Forestières (<http://www.sngf-madagascar.mg/> accessed 8 November 2014) have vazaha in their name.

[9] The impacts of *Acridotheres tristis* are not documented in Madagascar, as far as we know, though farmers interviewed stated it was a crop field pest (though not the worst). Elsewhere, the bird is known to compete with other bird species for food and nest sites, and to cause damage to crops, particularly fruits (Global Invasive Species Database, <http://www.issg.org/database/species/impact_info.asp?si=108&fr=1&sts=tss&lang=EN> accessed 20 November 2014).

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SUPPLEMENTARY MATERIAL.

AVAILABLE ONLINE ONLY.

FIGURE S1. Overlapping definitions of 'invasive species' in their broader, often social, context (by C. Kull).

TABLE S1. Summary of native, introduced, and invasive introduced species in Madagascar.