Reconciling conflicting perspectives for biodiversity conservation in the Anthropocene

Christoph Kueffer1 and Christopher N Kaiser-Bunbury2

We introduce a framework – based on experiences from oceanic islands – for conserving biodiversity in the Anthropocene. In an increasingly human-dominated world, the context for conservation-oriented action is extremely variable, attributable to three largely independent factors: the degree of anthropogenic change, the importance of deliberate versus inadvertent human influence on ecosystems, and land-use priorities. Given this variability, we discuss the need to integrate four strategies, often considered incompatible, for safeguarding biodiversity: maintaining relicts of historical biodiversity through intensive and continuous management; creating artificial in situ, inter situ, and ex situ conservation settings that are resilient to anthropogenic change; co-opting novel ecosystems and associated “opportunistic biodiversity” as the wildlife of the future; and promoting biodiversity in cultural landscapes by adapting economic activities.

In a nutshell:

* In human-dominated landscapes, conservation depends on reconciling conflicting concepts; preserving the qualities of historical (or pristine) nature will rely on human design, and novel ecosystems will dominate wildlands.
* Much biodiversity will survive only in “artificial” conservation habitat created through ex situ, inter situ, or in situ management.
* Rapid up-scaling of management efforts (including restoration) and rigorous prevention of threats are urgently needed to conserve relicts of historical biodiversity.
* Ultimately, maintenance of rare species, ecological interactions, and ecosystem services requires large-scale planning of mosaics of strictly protected areas, “artificial” biodiversity habitats, novel ecosystems, and biodiverse cultural landscapes.

1Institute of Integrative Biology, Swiss Federal Institute of Technology (ETH), Zurich, Switzerland (kueffer@env.ethz.ch); 2Department of Bioscience, Aarhus University, Aarhus, Denmark
Biodiversity conservation in the Anthropocene

It was traditionally accepted that biodiversity is conserved most effectively by protecting nature from human influence (cf Rosenzweig 2003; Kareiva et al. 2011). Because humans and their impacts are omnipresent, however, this view is becoming increasingly untenable. We believe that a new paradigm, based on three sets of considerations (Figure 1a), is required for guiding conservation efforts.

First, the historical abiotic and biotic conditions of habitats prior to major disturbances are an important reference for understanding and valuing the novel conditions that occur in human-influenced systems (Hobbs et al. 2013). Anthropogenic impacts on ecosystems have often resulted in biodiversity loss and homogenization. Understanding and quantifying these changes remains essential for determining and conserving the value of historical ecosystem characteristics under novel conditions.

Second, humans affect ecosystems either deliberately (eg land use) or inadvertently (eg climate change, invasive species, pollution). Deliberate actions can be altered and directed toward augmenting biodiversity conservation. Nature that is deliberately shaped by humans may be termed designed in contrast to wild (Higgs 2003; Kueffer and Daehler 2009). There thus exists a spectrum – from wildlands, which are scarcely affected by humans’ deliberate actions, to designed nature, which is deliberately influenced and created by humans. The negative effects of inadvertent actions on biodiversity appear to be increasing in most biomes of the world (MA 2005). This implies that, even in wild nature, historical habitat conditions are increasingly being lost as a result of past disturbances (eg fragmentation, small populations, loss of mutualisms, changed abiotic conditions) or unbounded anthropogenic effects. Consequently, historical habitat conditions can be conserved only through continuous major human intervention.

Third, in areas affected by deliberate human action,
conservation must take account of the prevailing types and spatial patterns of land use. This can result in another spectrum – from biodiversity areas, which are reserved exclusively for biodiversity conservation, to production land, where biodiversity is at best a byproduct of other land-use types.

Thus, conservation actions in a human-dominated landscape can be defined by three largely independent dimensions (Figure 1b): (1) historical to novel habitat conditions (abiotic and biotic), (2) wild to designed nature, and (3) biodiversity areas to production land. A framework that distinguishes these dimensions contrasts with traditional conservation thinking, which assumes that they are congruent: historical nature is to be found in wildlands that should be protected for the sole purpose of biodiversity conservation (Figure 1c). This changing perspective leads to at least four scenarios that are often considered conflicting (Figure 1d):

- Ways must be found to actively conserve remnants and values of historical nature that would cease to exist without direct human assistance. Depending on the intensity of interventions, the resulting state can be considered wild or designed.
- In a human-dominated world, biodiversity will depend on humans’ ability to create habitats through ex situ, inter situ, or in situ conservation that can withstand anthropogenic impacts and better ensure its persistence.
- Novel ecosystems are emerging that represent the wildlands of the future (ie the self-organized response of nature to anthropogenic impacts). Such ecosystems should be co-opted as part of biodiversity conservation.
- Cultural landscapes provide the opportunity to coproduce biodiversity through biodiversity-friendly and sustainable land-use schemes. This action falls within the remit of “reconciliation ecology” (Rosenzweig 2003) and “countryside biogeography” (Daily et al. 2001).

Conserving relicts of historical biodiversity requires rapid up-scaling of conservation efforts

A large proportion of island species persist today as isolated individuals or small populations in small habitat fragments (WebTable 1). Although these remnants may still harbor high levels of biodiversity (WebTable 1), much of it is likely to represent an extinction debt (Triantis et al. 2010). On many islands, major habitat damage has occurred only during the past 50 to 200 years, and the consequences of recent sharp declines in recruitment, especially for long-lived species, have not yet been fully realized. For example, regeneration of the palm Lodoicea maldivica has declined markedly in recent years but will be reflected in a declining adult population only after 200 to 300 years (Rist et al. 2010). Species that are restricted to one or a few small areas are also susceptible to stochastic events (Caujapé-Castells et al. 2010). Thus, outbreaks of pests and diseases may decimate populations of (even common) native species within a few years (Caujapé-Castells et al. 2010).

In the past, to conserve biodiversity meant primarily to restrict human interference in natural areas (cf Rosenzweig 2003; Kareiva et al. 2011). Now, as multiple threats affect historical biodiversity even in protected areas (Figure 2), active interventions must be undertaken speedily, applied at an adequate scale, and maintained indefinitely. Such intervention requires: (1) removing existing threats; (2) preventing further impacts; (3) reinforcing remnant populations, which are often too small to be viable; and (4) restoring vital ecological interactions and processes.

Recent advances in invasive species control and eradication on islands demonstrate that such rigorous actions can be effective (Veitch et al. 2011; Database of Island Invasive Species Eradications [http://eradicationsdb.fos. auckland.ac.nz/]). Eradication of invasive species from small- to medium-sized and sparsely populated islands has become a key element for the survival of critically endangered endemics (WebTable 2; Anderson et al. 2011). On large islands, a combination of containment, local eradication, and exclusion can have a dramatic positive effect on native biodiversity. For example, only 10 years after measures were introduced to control Psidium cattleianum in Conservation Management Areas on Mauritius, populations of many native plants and animals (some previously considered extinct) had re-emerged or increased.
Creating resilient habitat for conservation-reliant biodiversity

Despite efforts to conserve the least-disturbed habitat fragments, biodiversity on many islands will continue to decrease. To mitigate biodiversity losses, we recommend that natural areas be transformed to improve resilience or that novel habitats be created. Biodiversity that cannot be conserved in situ should be managed through an inter situ approach that conserves biodiversity in locations outside their past distribution but with the aim of maintaining essential ecological interactions (eg pollination, seed dispersal, trophic interactions; WebTable 2). More imminently, however, many species can be conserved only through ex situ management in botanical gardens and zoos (WebTable 2).

On most islands, biodiverse areas will be destroyed or degraded unless in situ management enhances the resilience of conservation-reliant biodiversity to anthropogenic change, which will require ecological design of biotic and abiotic conditions. Biological manipulation may involve the introduction and augmentation of “analogue” species closely related to extinct native species to restore ecological interactions (Hansen et al. 2010; Kaiser-Bunbury et al. 2010). For instance, Aldabra giant tortoises (Aldabrachelys gigantea) act as seed dispersers of the endemic ebony (Dispyros tessellaria) on Ile aux Aigrettes in Mauritius (Kaiser-Bunbury et al. 2010). Establishing a new balance in disturbed food webs may require introduction of alien species (eg biological control), or control or removal of specific native species (Sahasrabudhe and Motter 2011). Many of these tasks will necessitate continuous management efforts.

Inter situ conservation creates new spaces for imperiled species and biotic interactions associated with these species outside their original range (Burney and Burney 2007). These habitats and communities differ in the degree to which they resemble natural systems. The principal goal is to design ecosystems that are resilient to anthropogenic change and allow cost-effective conservation of multiple species. Examples include the Makawahi Cave restoration project in the Hawaiian Archipelago, in which native species are reintroduced to their former range (Burney and Burney 2007), and offshore islets in the Seychelles Archipelago (Panel 1), where inter situ communities consist of designed assemblages of threatened species (Kueffer et al. 2013). Although many conservationists still aim to ensure that reconstructed and original species assemblies are taxonomically and functionally similar, inter situ conservation areas on islands may increasingly be considered as refugia where biodiversity is preserved irrespective of historical communities (eg Towns et al. 1990). One example is the conservation of rocky inselberg (steep-sided monolithic outcrops) habitat in the Seychelles. Many tree species formerly present in lowland forest still survive as dwarf individuals in this ecologically marginal habitat (Kueffer et al. 2013). Conserving or actively introducing such moist forest trees to dry inselbergs, where some survive only as “bonsai” ecosystems of rocky habitats, could be considered a combination of in situ and inter situ conservation (Panel 1). Similarly, in situ and ex situ strategies merge when rare native species are planted in a park setting close to natural areas, which ensures maintenance of ecological interactions; for instance, after placement within a botanical garden, the rare endemic tree Colea seychellarum is pollinated by the endemic Seychelles sunbird Cinyris dussunieri visiting from nearby forests (Panel 1).

Novel ecosystems – a chance for wild nature and a need for containment

An increasing proportion of the world’s natural areas contain wild but disturbed habitat, especially on islands (WebTable 3). Such ecosystems have been termed “novel ecosystems” (Hobbs et al. 2013) and contain many alien or native species that thrive on anthropogenic disturbances (ie opportunistic biodiversity). Novel ecosystems and their opportunistic biodiversity deliver important ecosystem services, entail qualities of wildness, and ensure unrestricted evolution (WebTable 3; Kueffer and Daehler 2009; Carroll 2011; Hobbs et al. 2013). For example, forests in the Seychelles dominated by alien cinnamon (Cinnamomum verum) effectively prevent more problematic alien plant species from spreading, while allowing endemic plants to reproduce (Kueffer et al. 2010). In Hawaii, novel lowland forest maintains or increases ecosystem services such as productivity, nutrient turnover, or belowground carbon storage as compared with native stands (Mascaro et al. 2012). Further, novel ecosystems provide suitable habitat and functionally analogous ecological interactions, which allow some native species to persist despite detrimental change (Kueffer and Daehler 2009; Carroll 2011; Lugo et al. 2012). The introduced honey bee Apis mellifera, although often considered a competitor of endemic pollinators, is one of...
A major challenge of conservation in the Anthropocene is to integrate threatened biodiversity into a heterogeneous mosaic of habitats characterized by strongly contrasting anthropogenic, biotic, and environmental conditions (Koh and Gardner 2010). On islands, for instance, anthropogenic and environmental gradients are often steep, habitat fragments are small, and the distances between fragments are short. An illustrative example is Mahé, the 154-km$^2$ main inhabited island of the inner group of granitic islands of the Republic of Seychelles (western Indian Ocean; Kueffer et al. 2013). The island is divided into four broad habitat zones (Figure 3). Lowland regions from the coast to approximately 200 m above sea level (asl) are highly managed urban and agricultural areas characterized by tourism infrastructure along the coasts, urban development in the lowlands to approximately 100 m asl, and residential areas intermixed with abandoned secondary vegetation and private gardens to approximately 200 m asl (indicated in red in Figure 3). Biodiversity-poor, abandoned timber and cinnamon (Cinnamomum verum) plantations dominate an altitudinal belt between 200 m and 400 m asl (yellow in Figure 3). Between 400 m and 600 m asl, the island is covered almost entirely by abandoned cinnamon plantations (green in Figure 3). In contrast to lower elevations, these “novel” forests are still rich in native biodiversity, albeit scattered, and are mostly included within protected areas. Above approximately 600 m asl, 3 km$^2$ of montane cloud forest persists that is still composed of mostly native vegetation, although alien trees such as cinnamon are common (blue in Figure 3). Inselberg (“glacis”) are steep-sided monolithic rock outcrops that occur throughout the elevation gradient but primarily from 250 m to 650 m. Inselberg vegetation harbors some of the last remaining endemic plant communities in the Seychelles and consists of shrubs, small trees, palms, and screw palms (Pandanus sp). Each of these habitat zones provides particular opportunities for biodiversity conservation. In the populated lowland zone, ex situ propagation, in situ conservation, agroforestry, and ecotourism are important elements of conservation strategies. For instance, at the Barbarons Biodiversity Center, part of the Seychelles Botanical Gardens (Figure 3, polygon A), rare species are propagated and planted in a park-like setting bordering wildlands, which ensures that basic ecological interactions are maintained. North Island, a 210-ha island, is one example of the role of ecotourism in intertidal biodiversity conservation. The island is managed by a luxury hotel that is in the process of eradicating invasive species, restoring native vegetation, and reintroducing rare plant and animal species (Figure 3, arrow B). Abandoned plantation and cinnamon forest is currently underutilized and mostly unmanaged (Figure 3, polygon C). It holds promise for sustainable timber production and the harvesting of non-timber forest products, and as a managed forest it can serve as a buffer zone for high biodiversity areas. To manage the cinnamon-dominated novel forests at mid-elevations as a mixed native–alien forest, it has been proposed that small patches of native vegetation interspersed in the cinnamon forest should be restored (Figure 3, polygon D). Such patches would serve as native fruit sources for the surrounding forest while the alien matrix maintains important ecological functions for the forest (e.g., erosion control, food source for native fauna, barrier against other plant invasions; Kueffer et al. 2013). Inselberg vegetation is also a seed source of native species in the alien-dominated landscape. Managing and conserving rare plants on inselbergs, including some for which this habitat is only marginally suitable, may be considered a combination of in situ and inter situ conservation (Figure 3, polygon E). Only small pockets of montane cloud forest and mid-elevation native palm forest survive across the island (Figure 3, polygon F). These forests are imperiled by invasive plants and animals, climate change, and other human disturbances, and only continuous and intensive in situ management will be able to preserve these sensitive habitats.
the most abundant pollinators of many native island plants (Kaiser-Bunbury et al. 2010). Because some of these native plants have lost their endemic mutualisms, introduced honey bees now provide vital pollinator services. Similarly, alien birds and mammals often act as “substitute” seed dispersers for native plants (eg Riera et al. 2002).

Novel ecosystems and their opportunistic biodiversity are no panacea for biodiversity conservation, partly because many native species will not persist in novel habitats and opportunistic biodiversity may threaten to invade refugia of vulnerable native species. Despite its benefits to mid-elevation novel forests in the Seychelles, cinnamon threatens nearby montane cloud forests and must be prevented from spreading therein (Kueffer et al. 2013). Opportunistic biodiversity can also introduce problematic features to landscapes, such as increased fire risk. Because it is often unfeasable or undesirable to replace novel with native habitats (eg Kueffer et al. 2010; Carroll 2011; Hobbs et al. 2013), studying novel ecosystem functioning is essential to identify positive features that can be used in sustainable biodiversity management. Such management could, for instance, involve the large-scale replacement of problematic alien species, which invade nearby natural areas or increase fire risk, with easy to propagate native or less problematic alien species. If well managed, novel ecosystems may harbor valuable opportunistic native and alien biodiversity, facilitate evolution of new biodiversity, increase resilience to climate change, establish ecological connectivity, or act as buffer zones for high biodiversity areas, all of which can aid conservation.

Promoting biodiversity in cultural landscapes toward long-term coexistence

Another promising avenue for conservation is the promotion of native biodiversity in a cultural landscape and on production land (Daily et al. 2001; Rosenzweig 2003; Koh and Gardner 2010). Some island animals are ecologically plastic and can adapt to, or benefit from, man-made environments and new food sources (Kaiser-Bunbury et al. 2010; Lugo et al. 2012). For example, endemic geckos use coconut trees and domestic houses for shelter, and frugivorous endemic birds and fruit bats have expanded their diets to include alien fruits grown in gardens and plantations (eg Luskin 2010). To coproduce biodiversity, human activities such as landscaping, sustainable forest production, agroforestry, low-intensity agriculture, and home gardening have to be tailored to the needs of native species (eg Thaman 2002; Atkinson et al. 2010). One advantage of coproduced biodiversity is the provision of additional land for biodiversity conservation and its economically sustainable management (Rosenzweig 2003). For instance, invasive species control (eg of rats and weeds) on production land may benefit some conservation-reliant biodiversity that cannot be conserved on wildlands.

On islands, coproducing biodiversity in cultural landscapes is important for several reasons. First, distances between urban areas, agricultural land, and (semi-)natural areas are often very short (Panel 1), allowing native fauna to move between anthropogenic and natural areas for different activities (eg foraging and roosting; Luskin 2010). Second, maintenance of agriculture and (agro)-forestry is essential for economic and ecological sustainability, subsistence, and food security of island communities. Consequently, biodiversity-friendly land use such as indigenous land-use systems, agroforestry, or domestic gardens have a long tradition on islands (Esquivell and Hammer 1992; Clarke and Thaman 1993; Thaman 2002), and sustainable forestry with native tree species is increasingly being implemented (eg Baret et al. 2012). Third, ecotourism provides opportunities for landscaping with native biodiversity and cofinancing of conservation actions (Panel 1; eg Baret et al. 2012; Kueffer et al. 2013). In return, biodiversity-rich cultural landscapes can help to increase awareness of biodiversity among tourists and local citizens. Guiding and promoting the coexistence of production and biodiversity is thus integral to biodiversity conservation and sustainable development on islands.

Conclusions

More than 80% of conservation scientists agree that current conservation goals and standards of success should be reassessed (Rudd 2011). We have reviewed some of the new approaches that integrate traditional and novel perspectives. Most of these require a landscape-scale approach, with different types of management adapted to specific habitats (Panel 1), and a move beyond simplistic dichotomies such as wildlands versus man-made ecosystems. In essence, biodiversity conservation can be improved by embracing a multipronged approach, including: conserving relicts of historical biodiversity, creating artificial biodiversity conservation areas, co-opting novel ecosystems and their opportunistic biodiversity as a fundamental part of biodiversity conservation, and coproducing biodiversity in cultural landscapes.

The views proposed here should not distract attention from the immediate need to protect and restore remaining large tracts of relatively undisturbed wildlands on continents (Caro et al. 2012). Instead, lessons learned from island settings can equip managers with a broader set of skills and approaches to address emerging conservation challenges on continents. At a global scale, wildland extent is rapidly shrinking (Steffen et al. 2004; MA 2005; Koh and Gardner 2010; Hobbs et al. 2013) and vulnerable biodiversity is dependent on ever smaller fragments of natural areas (Gibson et al. 2011) while novel ecosystems are expanding (Hobbs et al. 2013); consequently, designing landscapescale mosaics of wild and anthropogenic nature is an emerging global conservation priority (Koh and Gardner 2010). In this sense, conservation on islands provides a preview of what conservation on continents may be like in the future.
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