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BIODIVERSITY REVIEW

Conservation opportunities across the world's anthromes

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ABSTRACT

Aim Biologists increasingly recognize the roles of humans in ecosystems. Subsequently, many have argued that biodiversity conservation must be extended to environments that humans have shaped directly. Yet popular biogeographical frameworks such as biomes do not incorporate human land use, limiting their relevance to future conservation planning. 'Anthromes' map global ecological patterns created by sustained direct human interactions with ecosystems. In this paper, we set to understand how current conservation efforts are distributed across anthromes.

Location Global.

Methods We analysed the global distribution of IUCN protected areas and biodiversity hotspots by anthrome. We related this information to density of native plant species and density of previous ecological studies. Potential conservation opportunities in anthromes were then identified through global analysis and two case studies.

Results Protected areas and biodiversity hotspots are not distributed equally across anthromes. Less populated anthromes contain a greater proportion of protected areas. The fewest hotspots are found within densely settled anthromes and wildlands, which occur at the two extremes of human population density. Opportunities for representative protection, prioritization, study and inclusion of native species were not congruent.

Main conclusions Researchers and practitioners can use the anthromes framework to analyse the distribution of conservation practices at the global and regional scale. Like biomes, anthromes could also be used to set future conservation priorities. Conservation goals in areas directly shaped by humans need not be less ambitious than those in 'natural areas'.

Keywords

Anthropocene, biome, human–environment interaction, land cover change, prioritization, protected area.

INTRODUCTION

An increasing number of organizations prioritize conservation projects by evaluating patterns of biodiversity and threats to biodiversity at the global scale (MA, 2005; Pereira *et al.*, 2013). In order to identify such patterns, researchers have analysed biomes – units that map differences in vegetation type associated with variation in temperature and precipitation (Whittaker, 1962) – and ecoregions – units that incorporate data on the distribution of flora and fauna to further divide biomes into 867 distinctive biological units (Olson *et al.*, 2001). These biogeographical frameworks have been used to identify areas of rapid habitat conversion (Hoekstra *et al.*, 2005), biologically distinctive areas (Ricketts *et al.*, 1999), mismatches between biological richness and endemism (Orme *et al.*, 2005; Lamoreux *et al.*, 2006) and patterns of ecosystem services provisioning (Naidoo *et al.*, 2008), among other global patterns. Conservation organizations

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use such information to identify locations for future acquisition or management (Brooks *et al.*, 2006). For example, Kier *et al.* (2005) mapped vascular plant species richness by ecoregion and compared these results with published literature on global priorities for plant conservation. Others have used biogeographical frameworks to identify 'gaps' in the coverage of protected areas (e.g. Rodrigues *et al.*, 2004).

But biomes, ecoregions and related biogeographical frameworks are limited in that they reduce human influences to a single dimension of disturbance. In the past fifteen years, an increasing number of conservation biologists have argued that biodiversity conservation must be extended to habitats directly shaped by humans (Table 1). Humans dwell on or use most of Earth's land surface, and human activities affect

Table 1 Examples of recent proposals asserting that future conservation actions must be extended to ecosystems directly shaped by humans and must embrace and leverage varying intensities of human activity

Proposal	Example citation	Description
1. Modifying human livelihood goals to incorporate and deliver on conservation goals		
Agroecology	Perrings *et al.* (2006)	Promote integrated study of the entire food system, including ecological, economic and human dimensions
Conservation in urban areas	McKinney (2002)	Develop ecologically informed public through study of urban ecology; design anthropogenic landscapes to promote biodiversity and ecosystem services
Ecosystem stewardship	Chapin *et al.* (2010)	Foster social–ecological sustainability on a rapidly changing planet
Land sharing/land sparing	Phalan *et al.* (2011)	Address biodiversity conservation alongside agronomic production goals
Reconciliation ecology	Rosenzweig (2003)	Redesign anthropogenic habitats so that their use is compatible with use by broad array of other species
2. Modifying conservation goals to deliver on human livelihood goals		
Ecosystem-based adaptation	Jones *et al.* (2012)	Use of biodiversity and ecosystem services to help people and communities adapt to the negative effects of climate change
Ecosystem services	Daily *et al.* (2009)	Give 'natural capital', which produces ecosystem services, adequate weight (monetary value) in decision-making processes
3. Redefining conservation goals given global change		
Conserving the stage	Anderson & Ferree (2011)	Implement conservation in a manner that maximizes potential evolutionary adaptive response to climate change as opposed to trying to save all species or picking winners
Ecological connectivity	Krosby *et al.* (2010)	Soften the matrix; increase connectivity to increase probability of persistence for many organisms as climate changes
Intervention ecology	Hobbs *et al.* (2011)	Rather than attempt to restore past systems, reinstate the capacity for ecosystem functions and processes
Managed relocation	Richardson *et al.* (2009)	Save species from effects of climate change by transporting them to areas where they have not previously occurred, also termed 'assisted colonization' and 'assisted migration'
Novel ecosystems	Seastedt *et al.* (2008)	Recognize new combinations of species under new abiotic conditions ('novel ecosystems') and focus on desired outcomes or trajectories
Realignment	Millar & Brubaker (2006)	Realign or entrain ecosystems with current and expected future conditions rather than restoring to historical pre-disturbance conditions
4. Enhancing conservation through community engagement		
Citizen science	Cooper *et al.* (2007)	Involve citizen participants directly in monitoring and management of residential lands to overcome 'tyranny of small decisions' to promote biodiversity
Community-based management	McNeely (1995)	Conservation planning, implementation, research, development and management must be done by local community as a whole; they must be the custodians and beneficiaries for success
Conservation banking	Fox and Nino-Murcia (2005)	Market that provides incentives for citizen stewardship by offering landowners opportunity to sell habitat or credits to protect private lands in perpetuity for mitigating loss of other habitat
Conservation easements and land trusts	Rissman *et al.* (2007)	Protection of private lands through easements (contract that divides portions of land title between the landowner and an easement holder) and trusts (organizations that acquire and manage easements)
Human–environment interactions	Miller (2005)	Design the places where people live and work to provide opportunities for meaningful interactions with the natural world
Planetary opportunities	DeFries *et al.* (2012)	Develop, evaluate, inform and advise society on potential pathways for sustainable development
Reserve as catalyst	Miller *et al.* (2012)	Describes a model of conservation and ecosystem stewardship that is cohesive across reserves and private lands

most ecological processes (Sanderson *et al.*, 2002; Foley *et al.*, 2005). The diversity of approaches presented in Table 1 reflects two tenets of conservation science (Kareiva & Marvier, 2012): first, that conservation planning should be approached through multiple strategies, and second, that humans should be considered part of ecosystems.

Responding to a need for biogeographical frameworks that incorporate human processes, an increasing number of researchers and practitioners are promoting the use of integrative global-scale models of human–environment interactions (Rindfuss *et al.*, 2004; Ellis *et al.*, 2013), including 'anthromes' (anthropogenic biomes) (Ellis & Ramankutty, 2008; Václavík *et al.*, 2013). Recently, the anthrome framework has been used to understand global ecological patterns, including the rate of landscape change over centuries (Ellis *et al.*, 2010) and patterns of plant diversity (Ellis *et al.*, 2012). Anthromes have also been used to highlight risks to threatened species resulting from human activity and to prioritize and direct conservation efforts in those areas. Kumara and Ramamoorthy (2011) identified anthromes in peninsular India and Sri Lanka that contained potential Travancore flying squirrel habitat. Pekin & Pijanowski (2012) combined a GIS database with distribution ranges for red-listed and non-threatened terrestrial mammal species from the IUCN with the anthromes dataset and found that the probability of endangerment increased for mammal species at the proportion of urban settlements and residential and populated croplands within their distribution ranges increased. Brum *et al.* (2013) found that an anthrome category (village) was a better predictor of the distribution of threatened amphibians than climate. The anthromes framework has also been suggested as a resource for conserving tropical forest biodiversity (Gardner *et al.*, 2009), guiding management of sustainable agricultural systems (Richter & Yaalon, 2012) and identifying the relationships between multiple ecosystem services across heterogeneous land uses (Bennett *et al.*, 2009).

Here, we use the anthrome framework to characterize current conservation efforts at the global scale. Similar analyses via biomes and ecoregions show a large bias in both the regional and global distribution of protected areas, which are concentrated primarily in areas that are at high elevations, far from human population centres or otherwise unsuitable for agriculture (Pressey, 1994; Wilson *et al.*, 2006; Joppa & Pfaff, 2009). Recognition of this bias in distribution has resulted in efforts to develop a more representative 'conservation portfolio' based on biogeographical patterns (e.g. Rodrigues *et al.*, 2004). Thus, a similar analysis under the anthrome framework will provide additional information to assure that conservation opportunities are not being missed or undervalued in coupled human–natural systems.

We begin by reviewing the human and ecological characteristics of anthromes as they pertain to biodiversity conservation. We then analyse the current global distribution of conservation efforts by anthrome, identifying underprotected, underprioritized and understudied anthromes. Through this global analysis, we identify anthromes that represent the greatest planetary opportunities (DeFries *et al.*, 2012) for biodiversity conservation. We then present two case studies in which the anthrome framework reveals novel conservation opportunities.

WHAT ARE ANTHROMES?

Biomes are defined by differences in vegetation type associated with regional variations in climate. But humans have transformed ecosystems across more than three-quarters of the terrestrial biosphere (Sanderson *et al.*, 2002). Anthromes (anthropogenic biomes) present an alternative view of the terrestrial biosphere by characterizing the rich diversity of global ecological land cover patterns created and sustained by human population densities and land use while also incorporating their relationships with biotic communities (Ellis & Ramankutty, 2008). For example, rather than describing the major food-, fibre- and fuel-producing regions of the world by their potential vegetation, anthromes classify these regions along gradients of population density and land use intensity to reveal ecologically important patterns (Fig. 1).

Anthromes were first mapped from global data for human population, land use and remotely sensed vegetation cover using a statistical classification algorithm by Ellis & Ramankutty (2008; 21 classes). To enable long-term global changes in anthromes to be mapped, the current rule-based anthrome classification model was developed using a simplified system of 19 anthromes (Ellis *et al.*, 2010).

Figure 1 presents a global map of contemporary anthromes, together with a conceptual diagram illustrating general patterns in human population densities and land use within and across anthromes, while also incorporating their relationships with biotic communities. Online maps and spatial data for anthromes are available for download at http://ecotope.org/anthromes/v2. Dense settlements and villages are the most populated and modified anthromes, encompassing ~70% of the global human population. Croplands, rangelands and semi-natural/forested anthromes are less densely populated but reflect significant land use change under human direction. Wildlands represent areas with little or no human activity; 85% of wildlands are located in cold and dry biomes (Ellis *et al.*, 2010).

Within all anthromes, including densely populated anthromes, humans rarely use all available land. As a result, anthromes are generally multifunctional mosaics of heavily used lands and less intensively used lands. Growing evidence indicates that viable populations of native plants may be sustainable within anthromes, at least at local and regional scales (Ellis *et al.*, 2012), but extending the mechanisms of conservation successes to other anthromes is necessary. Yet to date, no comparative work has explored how anthromes differ in their capacities to support biodiversity at all levels, for example species richness, functional diversity, genetic diversity (Pereira *et al.*, 2013).

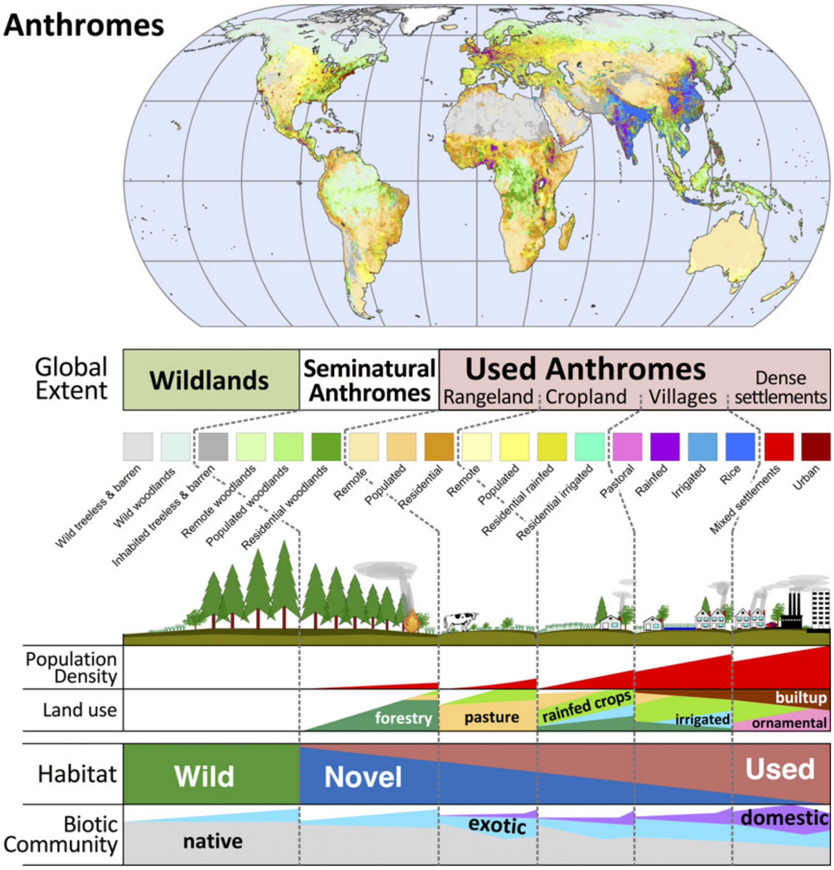

Figure 1 Global map of contemporary anthromes (top; year 2000) and associated socio-economic and ecological characteristics, including human population density, land use and integrity of habitat and biotic communities (bottom).

METHODS

In this paper, we analyse how four ecologically important distributions map onto anthromes: protected areas (IUCN categories I-VI), prioritized areas (biodiversity hotspots; Myers *et al.*, 2000), ecological study areas (Martin *et al.*, 2012) and native plant richness (Ellis *et al.*, 2012). We chose these four distributions based on their global scale, data quality and relevance to extant conservation literature. Together, they provide a snapshot of how current conservation efforts are distributed among anthromes.

We first determined the extent of protected area (IUCN categories I-VI) in each anthrome. IUCN protected areas span a wide range of protected statuses, from strict nature reserves to sustainable natural resource management areas, reflecting different intensities of human–environment interaction. Our use of ‘protected areas’ is liberal in the sense that some practitioners do not consider categories IV, V and VI to be truly protected, but is conservative in the sense that other instruments contribute to biodiversity conservation on lands not designated by IUCN status, including regulations on agricultural inputs, payments for ecosystem services, conservation easements and others.

We then determined the extent of prioritized area in each anthrome. Governments and NGOs currently employ many prioritization schemes (reviewed in Brooks *et al.*, 2006). Here, we explore biodiversity hotspots, defined as places where large numbers of endemic vascular plant and/or vertebrate species are undergoing extensive habitat (Myers *et al.*, 2000).

We next approximated how much research attention has been devoted to each anthrome by calculating the density of ecological field sites using a dataset developed by Martin *et al.* (2012). A lack of study may suggest the potential for missed biodiversity conservation opportunities. This dataset includes the spatial coordinates of the 1476 sites reported in papers published from June 2004 to June 2009 in ten top ecology journals. The dataset includes terrestrial field study sites situated world-wide, although these data are limited to studies published in English-language journals.

Finally, we calculated as the density (number km^{-2}) of extant native plant species in an anthrome following methods described in Ellis *et al.* (2012). This dataset represents the first spatially explicit integrated assessment of the anthropogenic global patterns of plant species richness created by the sustained actions of human populations at regional landscape scale. In future, similar datasets may be available for other taxa.

We classified anthromes using the algorithm and data inputs of Ellis *et al.* (2010) from global population and land use data stratified within a geodesic Icosahedral Snyder Equal Area discrete global grid system (DGG) with a cell area of

96 km^2 and intercell spacing of approximately 10.5 km (Level 12 DGG; Sahr *et al.*, 2003). The extent of protected areas within anthromes was calculated by overlaying the 2010 WDPA area shapefile (IUCN and UNEP-WCMC 2010) on the Level 12 DGG and calculating overlay areas using a geographical information system (GIS). Hotspot areas were calculated by applying the same approach using the Level 8 DGG anthrome dataset of Ellis *et al.* (2012; 7792 km^2 cells, intercell spacing of approximately 95 km) and the biodiversity hotspot maps of Mittermeier *et al.* (2003; 'Biodiversity Hotspots', Conservation International 2011 shapefile downloaded from: http://www.biodiversityhotspots.org/xp/Hotspots/resources/maps.xml [Accessed: 11/02/2012]). We used these results to rank anthromes by percentage protected area and percentage prioritized area.

We explored correlations between anthrome protection, prioritization, study and native species in JMP Pro 10 (SAS Institute Inc., Cary, NC, USA). We then characterized 'conservation opportunity' as being positively correlated with native species ranking and inversely correlated with protection, prioritization and study rankings; in other words, a lack of protection, prioritization or ecological research was taken to constitute a conservation opportunity. Finally, we summed each anthrome's four rankings to calculate a relative opportunity score for each anthrome. We then grouped anthromes into those of great conservation opportunity (1–6), moderate conservation opportunity (7–13) and lesser conservation opportunity (14–19).

RESULTS

Protected areas are not distributed equally across anthromes at the global scale (Fig. 2). In general, less populated anthromes contain a greater proportion of protected area. For example, while 23.4% of remote woodland anthrome area is protected, only 2.3% of irrigated village anthrome area is protected.

As with protected areas, biodiversity hotspots are not distributed equally across anthromes (Fig. 2). The fewest hotspots are found within densely settled anthromes and wildlands, which occur at the two extremes of human population density. For example, hotspots encompass 1.9% of wildland anthromes, 6.7% of densely settled (urban and mixed settlement) anthromes. The greatest extent of hotspots was found in residential rainfed croplands, encompassing 38.3% of the anthrome.

The least studied anthromes are rice villages, irrigated villages and remote rangelands (Table 2). Some of the anthromes with the greatest density of native plant species are populated anthromes, including pastoral villages, mixed settlements and urban areas (Table 2).

Opportunities for representative protection, prioritization, study and inclusion of native species are not necessarily congruent (Table 2). For example, although a large proportion of the wild treeless and barren anthrome is protected, this anthrome category also has a low density of native plant species and is not well studied. The rice village anthrome does not contain much protected area but is prioritized under the

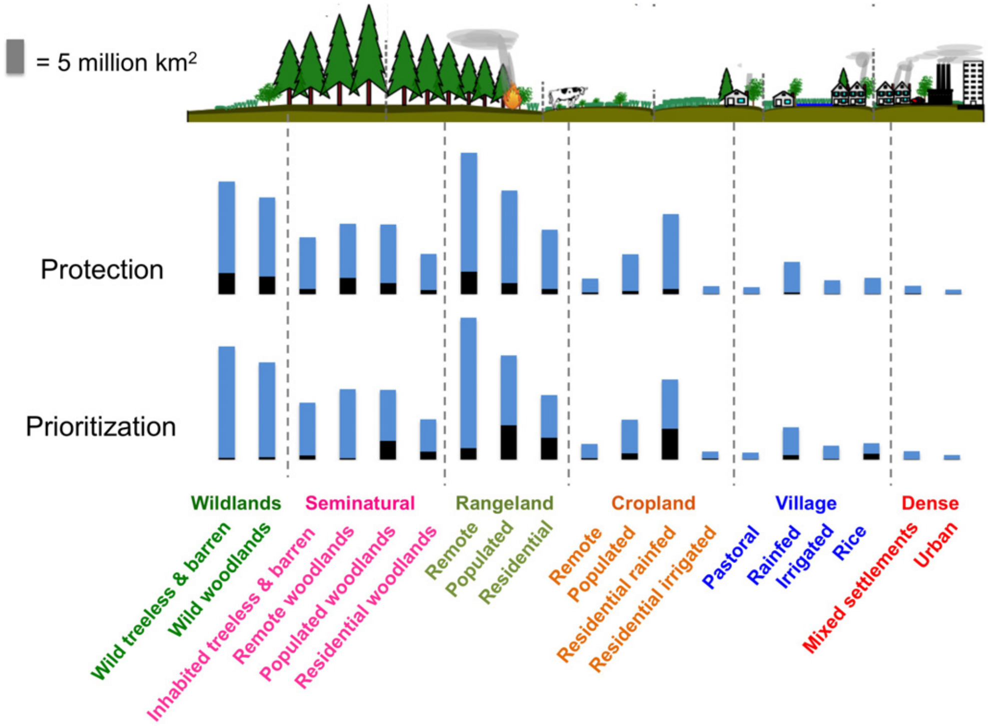

Figure 2 Blue bars show the total ice-free land area for each anthrome group, with the relative proportion of protected ('Protection') or priority hotspot ('Prioritization') areas shown in black. Anthromes are grouped by primary headings and subheadings.

Table 2 Anthromes ranked by opportunity for expanded representative protection, prioritization, study and density of native plant species. Those with the least opportunity are represented by '1', extending to those with the greatest opportunity as represented by '19'. The final column ('Opportunity') aggregates the four rankings into one categorical scale of conservation opportunity

Anthrome	Protection	Prioritization	Study	Native spp.	Opportunity
Wild treeless & barren	2	19	15	1	Moderate
Wild woodlands	3	18	11	2	Moderate
Inhabited treeless & barren lands	9	13	16	6	Great
Remote woodlands	1	17	14	15	Great
Populated woodlands	4	10	4	7	Less
Residential woodlands	7	9	3	11	Less
Remote rangelands	5	16	18	3	Moderate
Populated rangelands	6	6	13	4	Less
Residential rangelands	10	3	12	8	Less
Remote croplands	8	14	5	10	Moderate
Populated croplands	12	12	8	9	Moderate
Residential rainfed croplands	13	5	7	5	Less
Residential irrigated croplands	17	2	6	16	Moderate
Pastoral villages	15	4	9	19	Great
Rainfed villages	16	11	10	12	Great
Irrigated villages	19	15	17	14	Great
Rice villages	18	7	19	13	Great
Mixed settlements	11	1	2	18	Less
Urban	14	8	1	17	Moderate

biodiversity hotspot framework and contains a high density of native plant species. Similar to rice villages, populated and residential rangelands and residential croplands are prioritized but underprotected (Fig. 2). The ecologies of mixed settlements have yet to be explored in detail by ecologists, but these anthromes contain many native species and are relatively unprotected.

Among anthromes, proportion protected was negatively correlated with proportion prioritized under the biodiversity hotspot framework ($R^2 = 0.33$, $F_{1,17} = 8.34$, $P = 0.01$; Fig. 3a). In other words, an anthrome with a low proportion of protected area generally contained a high proportion of prioritized area. But proportion protected was unrelated to density of native plant species ($R^2 = 0.00$, $F_{1,17} = 0.00$, $P = 0.99$; Fig. 3c). Anthromes with a higher proportion prioritized under the biodiversity hotspot framework had a higher density of native plant species ($R^2 = 0.18$, $F_{1,17} = 3.72$, $P = 0.07$; Fig. 3c), but were not better studied by ecologists ($R^2 = 0.05$, $F_{1,17} = 0.95$, $P = 0.3424$; Fig. 3d).

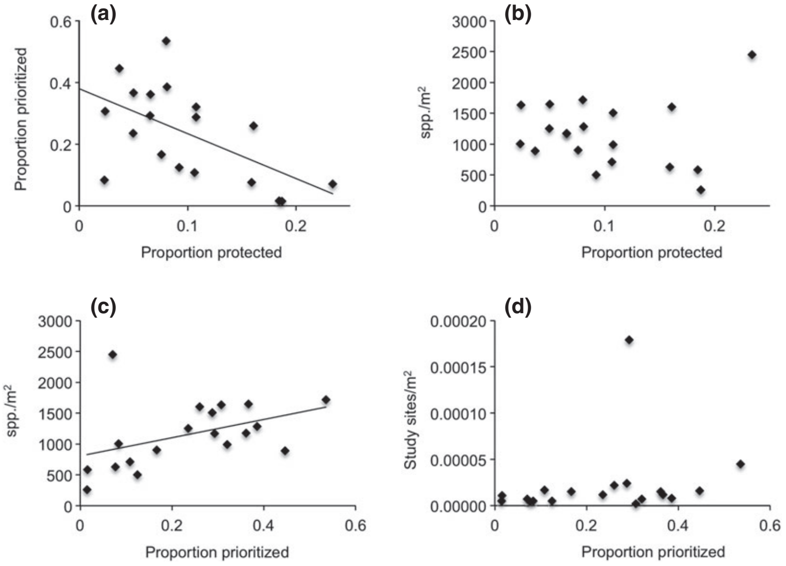

Figure 3 Relationships between proportion of anthrome prioritized under the biodiversity hotspot framework, proportion of anthrome protected, density of ecological study sites (sites m^{-2}) and density of native plant species (species m^{-2}).

IMPLICATIONS

At present, nine major institutional templates of global biodiversity conservation prioritization have been published (Brooks *et al.*, 2006). Most templates prioritize high irreplaceability, but some prioritize high vulnerability and some prioritize low vulnerability – hence priority maps cover from less than one-tenth to more than one-third of the Earth's land surface. Four of these templates incorporate measures of habitat loss (Myers *et al.*, 2000; Sanderson *et al.*, 2002; Mittermeier *et al.*, 2003; Hoekstra *et al.*, 2005). Two incorporate measures of human population size (Olson & Dinerstein, 1998; Hoekstra *et al.*, 2005). The rest do not consider human presence. But conservation biologists are increasingly prioritizing biodiversity in inhabited areas (Table 1), as are researchers in landscape planning, global change biology, agricultural science and other disciplines. Could conservation organizations use anthromes to reconsider the distribution of their projects and priorities?

Here, we demonstrate that it is possible to map multiple proxies of conservation effort by anthrome. Assuming that proportional representation by area is desirable, and weighting lack of previous prioritization, lack of previous protection, lack of previous study and density of native plant species equally, our analyses suggest that many current conservation opportunities are available within pastoral villages, rainfed villages, irrigated villages, rice villages, inhabited treeless and barren lands, and remote woodlands (Table 2). Of course, proportional representation by area across equally weighted metrics is only one of many ways to set priorities. Once an organization decides what characteristics to weight (e.g. irreplaceability, species richness) they could employ the same methods to identify anthromes of concern.

Maps of the world's anthromes enable researchers to communicate information regarding the status of global biodiversity over space and time. As a biogeographical framework, anthromes convey the conjoined fates of human populations and those of other species around the globe. Perceiving all anthromes as ecologically valuable, worthy of conservation effort and connected highlights positive actions that can be taken in landscapes previously underemphasized by conservationists.

APPLICATIONS

The anthrome framework links geographically far-flung areas that, under other frameworks, would not be considered together (e.g. agroforestry in temperate and tropical populated croplands). If ecologists and conservation biologists view the world as anthromes, then new questions can be asked to study patterns in species diversity, occupancy and abundance. For example, how similar are the ecological processes and threats to biodiversity within any anthrome type across diverse environmental contexts and human cultures? Do certain anthromes present greater opportunities for ecological connectivity than others? What lessons from one anthrome that has been extensively researched (e.g. rangelands) can be applied to understudied anthromes (e.g. rice villages)?

Consider the case of the western burrowing owl (*Athene cunicularia hypugaea*) in the Sonoran Desert ecoregion. The Imperial Valley in California has been dramatically altered by agriculture and development and is now primarily rangeland and cropland (Fig. 4a). Yet, this region provides important habitat for the burrowing owl, harbouring approximately 70% of the state's population (DeSante *et al.*, 2007). Research or management action would be constrained if

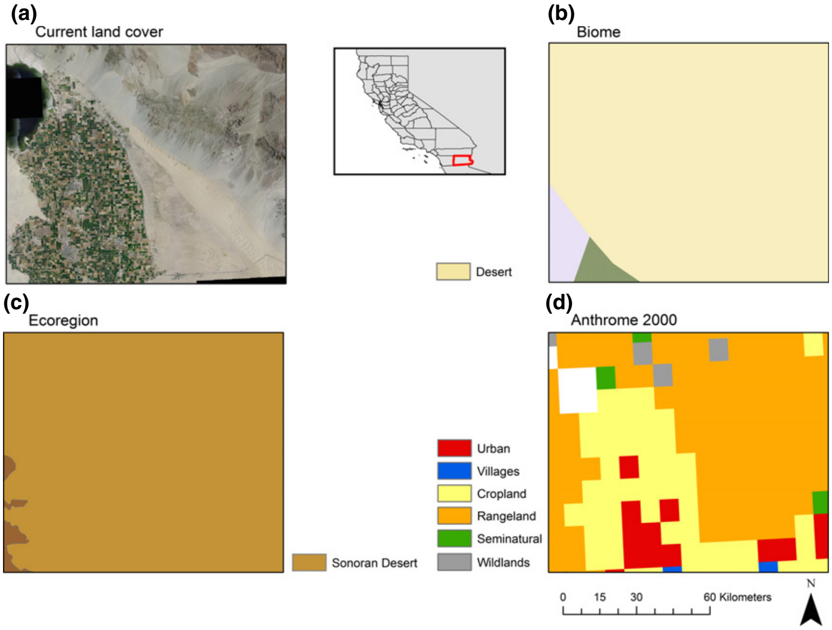

Figure 4 The Imperial Valley in southern California represented by (a) current land cover, (b) biome, (c) ecoregion and (d) anthrome.

framed under a biome or ecoregion framework, neither of which incorporates data on human land uses (Fig. 4b,c). Alternatively, a map of anthromes accounts for the dynamic and significant human land uses in this area (Fig. 4d) and draws parallels between the Imperial Valley and other anthromes encompassing mixed agricultural lands where unique conservation solutions exist (Quinn, 2013).

With anthromes as a backdrop, new conservation partners may be identified and new restoration techniques harnessed to extend western burrowing owl habitat into additional cropland and rangeland areas. Burrowing owls thrive on the abundant prey animals attracted to croplands and rangelands, but are limited by the lack of burrows created by fossorial mammals (Moulton *et al.*, 2006) because intensive efforts at rodent eradication throughout croplands, rangelands and densely settled anthromes have decimated these small mammals (Marsh, 1987). In many areas, invasive annual grasses have also decreased the available habitat for fossorial mammals, and a subsequent decline in their populations has been implicated as a key factor for the decline of burrowing owls (Machicote *et al.*, 2004). In surrounding cropland, rangeland and urban anthromes, efforts to re-establish fossorial mammals and to reduce invasive grass cover could increase habitat available to western burrowing owls. Other conservation-dependent grassland species could also benefit from efforts that are not solely focused on restoration of native habitat in wildlands.

Anthromes also provide a mechanism to identify conservation opportunities beyond known historical ranges. The California black rail (*Laterallus jamaicensis coturniculus*) made California's endangered species list following the conversion of San Francisco Bay-Delta Estuary tidal marshes to urban development. Thus, it was a surprise when a breeding population was documented (Aigner *et al.*, 1995) 130 km away in Sierra Nevada rangeland (Fig. 5a), a wildland anthrome 200 years earlier (Fig. 5b). The existence of this coastal species in non-tidal marshes forced the question: how does a bird species with a perceived tidal marsh habitat requirement survive in central California? Surveys revealed that wetlands created by leaking irrigation systems provided permanent marshes necessary to sustain the endangered population and a clear instance where a wildland would not have benefited the target species. As a consequence, management recommendations and emerging policy requirements are stipulating that ranchers leave some inefficiencies (i.e. leaks) in their irrigation systems.

These brief examples highlight opportunities that would not be evident under previous biogeographical frameworks. In each case, anthromes provide a framework to simultaneously consider human activity and ecological processes and to compare conservation solutions between ecoregions (but within anthromes). Thus, the challenge is to identify the mechanisms of success in these examples and transfer them to other complex conservation situations.

CONCLUSION

Caro *et al.* (2012) have argued that acknowledgement of the Anthropocene may 'cultivate hopelessness in those dedicated to conservation' and excuse, or even facilitate, land use for profit. Others worry that younger generations will accept increasingly degraded environments because of 'shifting baselines' (Papworth *et al.*, 2008). Alternatively, we suggest that anthrome analyses can clarify the complementary roles that conservation areas and actions can have within the biosphere. Mounting evidence is available to suggest that biodiversity conservation can be effective in both densely and sparsely settled anthromes (see references in Table 1), and biologists are increasingly questioning whether conservation goals in areas directly shaped by humans should remain less ambitious than those in 'natural areas'. Current work seeks to address whether goals such as ecosystem services and native species preservation can be bundled (e.g. Turner *et al.*, 2007), although, as Naidoo *et al.* (2008) suggest, more research is needed to evaluate the spatial concordance between areas that produce ecosystem services and those that support biodiversity. The anthromes framework could connect biodiversity conservation with extant policy instruments that focus on environment and human health outcomes in more densely populated or managed anthromes, such as payments for ecosystem services (e.g. reforestation, cropland fallowing), cost-share programmes (e.g. riparian buffers) and multistakeholder management initiatives (e.g. private lands forestry planning).

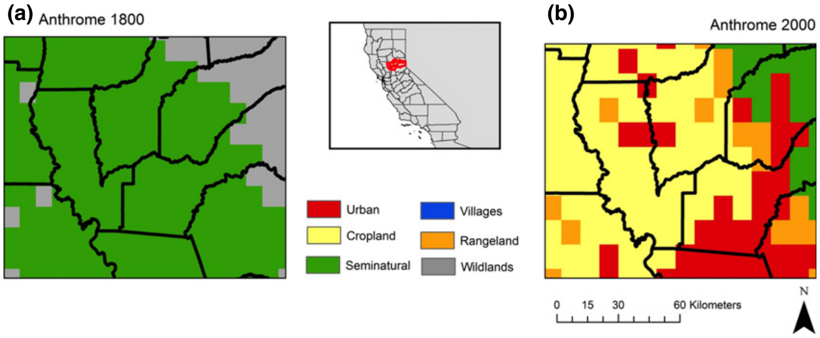

Figure 5 Changes in anthrome conditions relevant to conservation of the California black rail from (a) 1800 to (b) 2000.

As indicated in Fig. 1, human populations tend to be concentrated in the more biodiverse regions of the Earth. Furthermore, human populations are expected to grow until at least mid-century, while per capita demand for the products of agricultural landscapes will likely increase even faster (Foley *et al.*, 2011). Anthromes prioritized but not protected (e.g. populated and residential rangelands, residential croplands, rice villages; Fig. 2) represent areas where working outside of protected areas is most important. Ultimately, a conservation future built on maps that ignore human influences would result in missed opportunities, or a narrower field of conservation partnerships that excludes farmers, ranchers and others with an interest in conserving biodiversity in working landscapes. Rethinking the current distribution of conservation efforts by anthrome allows society to expand the horizons of biodiversity conservation. Human activity can sometimes benefit ecosystems – indeed, conservation itself is a human activity.

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REFERENCES

Aigner, P.A., Tecklin, J. & Koehler, C.E. (1995) The Black Rail in Yuba County, California. *Western Birds*, **26**, 157–160.

Anderson, M.G. & Ferree, C.E. (2011) Conserving the stage: climate change and the geophysical underpinnings of species diversity. *PLoS ONE*, **5**, e11554.

Bennett, E.M., Peterson, G.D. & Gordon, L.J. (2009) Understanding relationships among multiple ecosystem services. *Ecology Letters*, **12**, 1394–1404.

Brooks, T.M., Mittermeier, R.A., da Fonseca, G.A., Gerlach, J., Hoffmann, M., Lamoreux, J.F., Mittermeier, C.G., Pilgrim, J.D. & Rodrigues, A.S. (2006) Global biodiversity conservation priorities. *Science*, **313**, 58–61.

Brum, F.T., Gonçalves, L.O., Cappelatti, L., Carlucci, M.B., Debastiani, V.J., Salengue, E.V., Seger, G.D.S., Both, C., Berdardo-Silva, J.S., Loyola, R.D. & da Silva Duarte, L. (2013) Land use explains the distribution of threatened new world amphibians better than climate. *PLoS ONE*, **8**, e60742.

Caro, T., Darwin, J., Forrester, T., Ledoux-Bloom, C. & Wells, C. (2012) Conservation in the anthropocene. *Conservation Biology*, **26**, 185–188.

Chapin, F.S., Carpenter, S.R., Kofinas, G., Folke, C., Abel, N., Clark, W., Olsson, P., Smith, D.M., Walker, B., Young, O., Berkes, F., Biggs, R., Grove, J., Naylor, R., Pinkerton, E., Steffen, W. & Swanson, F. (2010) Ecosystem stewardship: sustainability strategies for a rapidly changing planet. *Trends in Ecology and Evolution*, **25**, 241–249.

Cooper, C.B., Dickinson, J., Phillips, T. & Bonney, R. (2007) Citizen science as a tool for conservation in residential ecosystems. *Ecology and Society*, **12**, 1–11.

Daily, G.C., Polasky, S., Goldstein, J., Kareiva, P.M., Mooney, H.A., Pejchar, L., Ricketts, T.H., Salzman, J. & Shallenberger, R. (2009) Ecosystem services in decision making: time to deliver. *Frontiers in Ecology and the Environment*, **7**, 21–28.

DeFries, R.S., Ellis, E.C., Chapin, F.S., Matson, P.A., Turner, B.L., Agrawal, A., Crutzen, P., Field, C., Gleick, P., Kareiva, P., Lambin, E., Liverman, D., Ostrom, E., Sanchez, P.A. & Syvitski, J. (2012) Planetary opportunities: a social contract for global change science to contribute to a sustainable future. *BioScience*, **62**, 603–606.

DeSante, D.F., Ruhlen, E.D. & Scalf, R. (2007) The distribution and relative abundance of burrowing owls in California during 1991–1993: Evidence for a declining population and thoughts on its conservation. *Proceedings of the California Burrowing Owl Symposium* (ed. by J.H. Barclay, K.W. Hunting, J.L. Lincer, J. Linthicum and T.A. Roberts), pp. 1–41. The Institute for Bird Populations and Albion Environmental, Inc., Point Reyes Station, CA.

Ellis, E.C. & Ramankutty, N. (2008) Putting people in the map: anthropogenic biomes of the world. *Frontiers in Ecology and the Environment*, **6**, 439–447.

Ellis, E.C., Goldewijk, K.K., Siebert, S., Lightman, D. & Ramankutty, N. (2010) Anthropogenic transformation of the biomes, 1700 to 2000. *Global Ecology and Biogeography*, **19**, 589–606.

Ellis, E.C., Antill, E.C. & Kreft, H. (2012) All is not loss: plant biodiversity in the anthropocene. *PLoS ONE*, **7**, e30535.

Ellis, E.C., Kaplan, J.O., Fuller, D.Q., Vavrus, S., Klein, K., Goldewijk, K. & Verburg, P.H. (2013) Used planet: a global history. *Proceedings of the National Academy of Sciences USA*, **110**, 7978–7985.

Foley, J.A., DeFries, R., Asner, G.P., Barford, C., Bonan, G., Carpenter, S.R., Chapin, F.S., Coe, M.T., Daily, G.C., Gibbs, H.K., Helkowski, J.H., Holloway, T., Howard, E.A., Kucharik, C.J., Monfreda, C., Patz, J.A., Prentice, I.C., Ramankutty, N. & Snyder, P.K. (2005) Global consequences of land use. *Science*, **309**, 570–574.

Foley, J.A., Ramankutty, N., Brauman, K.A. *et al.* (2011) Solutions for a cultivated planet. *Nature*, **478**, 337–342.

Fox, J. & Nino-Murcia, A. (2005) Status of species conservation banking in the United States. *Conservation Biology*, **19**, 996–1007.

Gardner, T.A., Barlow, J., Chazdon, R., Ewers, R.M., Harvey, C.A., Peres, C.A., & Sodhi, N.S. (2009) Prospects for tropical forest biodiversity in a human-modified world. *Ecology Letters*, **12**, 561–582.

Hobbs, R.J., Hallett, L.M., Ehrlich, P.R. & Mooney, H.A. (2011) Intervention ecology: applying ecological science in the twenty-first century. *BioScience*, **61**, 442–450.

Hoekstra, J.M., Boucher, T.M., Ricketts, T.H. & Roberts, C. (2005) Confronting a biome crisis: global disparities of habitat loss and protection. *Ecology Letters*, **8**, 23–29.

Jones, H.P., Hole, D.G. & Zavleta, E.S. (2012) Harnessing nature to help people adapt to climate change. *Nature Climate Change*, **2**, 504–509.

Joppa, L.N. & Pfaff, A. (2009) High and far: biases in the location of protected areas. *PLoS ONE*, **4**, e8273.

Kareiva, P. & Marvier, M. (2012) What is conservation science? *BioScience*, **62**, 962–969.

Kier, G., Mutke, J., Dinerstein, E., Rickets, T.H., Wolfgang, K., Holger, K. & Barthlott, W. (2005) Global patterns of plant diversity and floristic knowledge. *Journal of Biogeography*, **32**, 1–10.

Krosby, M., Tewksbury, J., Haddad, N.M. & Hoekstra, J. (2010) Ecological connectivity for a changing climate. *Conservation Biology*, **24**, 1686–1689.

Kumara, H.N. & Ramamoorthy, S. (2011) Predicting the potential distribution and conservation needs of Travancore flying squirrel, Petinomys fuscocapillus, in Peninsular India and Sri Lanka, using GARP. *Tropical Conservation Science*, **4**, 172–186.

Lamoreux, J.F., Morrison, J.C., Ricketts, T.H., Olson, D.M., Dinerstein, E., McKnight, M.W. & Shugart, H.H. (2006) Global tests of biodiversity concordance and the importance of endemism. *Nature*, **440**, 212–214.

MA (Millennium Ecosystem Assessment) (2005) *Ecosystems and human well-being: a framework for assessment. General synthesis*. Island Press, Washington, DC.

Machicote, M., Branch, L.C. & Villarreal, D. (2004) Burrowing owls and burrowing mammals. Are ecosystem engineers interchangeable as facilitators? *Oikos*, **106**, 527–535.

Marsh, R.E. (1987) Ground squirrel control strategies. *Californian agriculture: control of mammal pests* (eds by C.G.J. Richards and T.Y. Ku), pp. 261–276. Taylor and Francis, Inc., New York.

Martin, L.J., Blossey, B. & Ellis, E.C. (2012) Mapping where ecologists work: biases in the global distribution of terrestrial ecological observations. *Frontiers in Ecology and the Environment*, **10**, 195–201.

McKinney, M.L. (2002) Urbanization, biodiversity, and conservation. *BioScience*, **52**, 883–890.

McNeely, J.A. (1995) *Expanding partnerships in conservation*. Island Press, Washington, DC.

Millar, C.I. & Brubaker, L.B. (2006) Climate change and paleoecology: new contexts for restoration ecology. *Foundations of restoration ecology* (eds by D.A. Falk, M.A. Palmer and J.B. Zedler), pp. 315–340. Island Press, Washington, DC.

Miller, J.R. (2005) Biodiversity conservation and the extinction of experience. *Trends in Ecology and Evolution*, **20**, 430–434.

Miller, J.R., Morton, L.W., Engle, D.M., Debinski, D.M. & Harr, R.N. (2012) Nature reserves as catalysts for landscape change. *Frontiers in Ecology and the Environment*, **10**, 144–152.

Mittermeier, R.A., Mittermeier, C.G., Brooks, T.M., Pilgrim, J.D., Konstand, W.R., da Fonseca, G.A.B. & Kormos, C. (2003) Wilderness and biodiversity conservation. *Proceedings of the National Academy of Sciences USA*, **100**, 10309–10313.

Moulton, C.E., Brady, R.S. & Belthoff, J.R. (2006) Associations between wildlife and agriculture: underlying mechanisms and implications in burrowing owls. *Journal of Wildlife Management*, **70**, 708–716.

Myers, N., Mittermeier, R.A., Mittermeier, C.G., da Fonseca, G.A.B. & Kent, J. (2000) Biodiversity hotspots for conservation priorities. *Nature*, **403**, 853–858.

Naidoo, R., Balmford, A., Costanza, R., Fisher, B., Green, R.E., Lehner, B., Malcolm, T.R. & Ricketts, T.H. (2008) Global mapping of ecosystem services and conservation priorities. *Proceedings of the National Academy of Sciences USA*, **105**, 9495–9500.

Olson, D.M. & Dinerstein, E. (1998) The Global 200: a representation approach to conserving the Earth's most biologically valuable ecoregions. *Conservation Biology*, **12**, 502–515.

Olson, D.M., Dinerstein, E., Wikramanayake, E.D., Burgess, N.D., Powell, G., Underwood, E.C., D'Amico, J.A., Itoua, I., Strand, H., Morrison, J., Loucks, C., Allnutt, T., Ricketts, T.J., Kura, Y., Lamoreux, J.F., Wettengel, W.W., Hedao, P. & Kassem, K.R. (2001) Terrestrial ecoregions of the worlds: a new map of life on earth. *BioScience*, **51**, 933–938.

Orme, C.F.L., Davies, R.G., Burgess, M., Eigenbrod, F., Pickup, N., Olson, V.A., Webster, A.J., Ding, T., Rasmussen, P.C., Ridgely, R.S., Stattersfield, A.J., Bennett, P.M., Blackburn, T.M., Gaston, K.J. & Owens, I.P.F. (2005) Global hotspots of species richness are not congruent with endemism or threat. *Nature*, **436**, 1016–1019.

Papworth, S.K., Rist, J., Coad, L. & Milner-Gulland, E.J. (2008) Evidence for shifting baseline syndrome in conservation. *Conservation Letters*, **2**, 93–100.

Pekin, B.K. & Pijanowski, B.C. (2012) Global land use intensity and the endangerment status of mammal species. *Diversity and Distributions*, **18**, 909–918.

Pereira, H.M., Ferrier, S., Walters, M., Geller, G.N., Jongman, R.H.G., Scholes, R.J., Bruford, M.W., Brummitt, N., Butchart, S.H.M. & Cardoso, A.C. (2013) Essential biodiversity variables. *Science*, **339**, 277–278.

Perrings, C., Jackson, L., Bawa, K., Brussaard, L., Brush, S., Gavin, T., Papa, R., Pascual, U. & De Ruiter, P. (2006) Biodiversity in agricultural landscapes: saving natural capital without losing interest. *Conservation Biology*, **20**, 263–264.

Phalan, B., Onial, M., Balmford, A. & Green, R.E. (2011) Reconciling food production and biodiversity conservation:

land sharing and land sparing compared. *Science*, **333**, 1289–1291.

Pressey, R.L. (1994) Ad hoc reservations: forward or backward steps in developing representative reserve systems? *Conservation Biology*, **8**, 662–668.

Quinn, J.E. (2013) Sharing a vision for biodiversity conservation and agriculture. *Renewable Agriculture and Food Systems*, **28**, 93–96.

Richardson, D.M., Hellmann, J.J., McLachlan, J. *et al.* (2009) Multidimensional evaluation of managed relocation. *Proceedings of the National Academy of Sciences USA*, **106**, 9721–9724.

Richter, D.D. & Yaalon, D.H. (2012) "The changing model of soil" revisited. *Soil Science Society of America Journal*, **76**, 766–778.

Ricketts, T.H., Dinerstein, E., Olson, D.M., Loucks, C.J., Eichbaum, W., DellaSalla, D., Kavanagh, K., Hedao, P., Hurley, P. & Carney, K. (1999) *Terrestrial ecoregions of North America: a conservation assessment*. Island Press, Washington, DC.

Rindfuss, R.R., Walsh, S.J., Turner, B.L., Fox, J. & Mishra, V. (2004) Developing a science of land change: challenges and methodological issues. *Proceedings of the National Academy of Sciences USA*, **101**, 13976–13981.

Rissman, A.R., Lozier, L., Comendant, T., Kareiva, P., Kiesecker, J.M., Shaw, M.R. & Merenlender, A.M. (2007) Conservation easements: biodiversity protection and private use. *Conservation Biology*, **21**, 709–718.

Rodrigues, A.S.L., Andelman, S.J., Bakarr, M.I. *et al.* (2004) Effectiveness of the global protected area network in representing species diversity. *Nature*, **428**, 640–643.

Rosenzweig, M.L. (2003) Reconciliation ecology and the future of species diversity. *Oryx*, **37**, 194–205.

Sahr, K., White, D. & Kimerling, A. (2003) Geodesic discrete global grid systems. *Cartography and Geographic Information Science*, **30**, 121–134.

Sanderson, E.W., Jaiteh, M., Levy, M.A., Redford, K.H., Wannebo, A.V. & Woolmer, G. (2002) The human footprint and the last of the wild. *BioScience*, **52**, 891–904.

Seastedt, T.R., Hobbs, R.J. & Suding, K.N. (2008) Management of novel ecosystems: are novel approaches required? *Frontiers in Ecology and the Environment*, **6**, 547–553.

Turner, W.R., Brandon, K., Brooks, T.M., Costanza, R., Da Fonseca, G.A.B. & Portela, R. (2007) Global conservation of biodiversity and ecosystem services. *BioScience*, **57**, 868–873.

Václavík, T., Lautenbach, S., Kuemmerle, T. & Seppelt, R. (2013) Mapping global land system archetypes. *Global Environmental Change*, **23**, 1637–1647.

Whittaker, R.H. (1962) Classification of natural communities. *The Botanical Review*, **28**, 1–239.

Wilson, K.A., McBride, M.F., Bode, M. & Possingham, H.P. (2006) Prioritizing global conservation efforts. *Nature*, **440**, 337–340.

BIOSKETCH

This working group comprises fourteen members from twelve research institutions across the United States and Australia. It comes out of the Ecological Society of America Emerging Issues meeting, 'Developing Conservation Targets under Global Change' (http://www.esa.org/pdfs/EmergingIssuesConference2012Program.pdf). The group aims to synthesize anthropogenic biomes (anthromes) and conservation data. All authors contributed to conceptual development and manuscript. L. J. Martin and J. E. Quinn led the working group and manuscript preparation.

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