Biological Conservation 177 (2014) 12–24

Contents lists available at ScienceDirect

Biological Conservation

journal homepage: www.elsevier.com/locate/biocon

Remaining natural vegetation in the global biodiversity hotspots

Sean Sloan [a,*], Clinton N. Jenkins [b], Lucas N. Joppa [c], David L.A. Gaveau [d], William F. Laurance [a]

[a] Centre for Tropical Environmental and Sustainability Science, School of Marine and Tropical Biology, James Cook University, Cairns, Queensland 4870, Australia
[b] Department of Biological Sciences, North Carolina State University, Raleigh, NC 27695, USA
[c] Computational Science Laboratory, Microsoft Research, Cambridge CB1 2FB, UK
[d] Centre for International Forestry Research, Bogor 16000, Indonesia

ARTICLE INFO

Article history:
Received 15 February 2014
Received in revised form 19 May 2014
Accepted 27 May 2014

Keywords:
Biodiversity
Biodiversity hotspots
Conservation planning
Natural areas
Wilderness

ABSTRACT

The biodiversity hotspots are 35 biogeographical regions that have both exceptional endemism and extreme threats to their vegetation integrity, and as such are global conservation priorities. Nonetheless, prior estimates of natural intact vegetation (NIV) in the hotspots are generally imprecise, indirect, coarse, and/or dated. Using moderate- and high-resolution satellite imagery as well as maps of roads, settlements, and fires, we estimate the current extent of NIV for the hotspots. Our analysis indicates that hotspots retain 14.9% of their total area as NIV (~3,546,975 km^2). Most hotspots have much less NIV than previously estimated, with half now having ⩽10% NIV by area, a threshold beneath which mean NIV patch area declines precipitously below 1000 ha. Hotspots with the greatest previous NIV estimates suffered the greatest apparent losses. The paucity of NIV is most pronounced in biomes dominated by dry forests, open woodlands, and grasslands, reflecting their historic affinities with agriculture, such that NIV tends to concentrate in select biomes. Low and declining levels of NIV in the hotspots underscore the need for an urgent focus of limited conservation resources on these biologically crucial regions.

1. Introduction

The biodiversity hotspots are 35 biogeographic regions that cover 17.3% of the Earth's land surface (excluding Antarctica) and are characterized by both exceptional biodiversity and acute land-cover disturbance (Mittermeier et al., 2004; Myers et al., 2000). They are, in short, where human settlement, biological richness, and environmental degradation converge (Williams, 2013). Within the hotspots are over 2 billion people (Landscan, 2006; Mittermeier et al., 2011, 2004) increasing at higher-than-average rates (Cincotta et al., 2000; Williams, 2013), and an estimated 85% human-modified landscapes by area (Mittermeier et al., 2004). Hotspots sustain ~77% of all mammal, bird, reptile and amphibian species, including 50% of all plant species and 42% of terrestrial vertebrate species as endemics (Mittermeier et al., 2004), as well as three-quarters of all endangered terrestrial vertebrates (Brooks et al., 2002; Mittermeier et al., 1998, 2004). Cultural diversity is also high in the hotspots, with half of all indigenous languages found therein (Gorenflo et al., 2012).

Since the seminal publication of Myers et al. (2000) the concept of hotspots as focal points for global conservation action has become one of the foremost global conservation-prioritisation paradigms (Mittermeier et al., 2011). The concept has attracted over $1 billion in conservation investment from entities like the Critical Ecosystem Partnership Fund (i.e., World Bank, Global Environment Facility, and The Governments of Japan, France and Europe), The MacArthur Foundation, The Global Conservation Fund (i.e., Moore Foundation), Conservation International and its affiliated TEAM Program and Centers for Biodiversity Conservation, among many others (Dalton, 2000; Mittermeier et al., 2011, 1998, 2004; Myers, 2003; Myers and Mittermeier, 2003). These entities have explicitly adopted the hotspot concept as a central conservation-investment strategy. Whether or not the concept has garnered the "largest [monetary] sum ever assigned to a single conservation strategy" (Myers, 2003), its global traction and legacy are indisputable.

While it is accepted that primary vegetation has been widely disturbed in the hotspots and globally (Vitousek et al., 1997), precise estimates of remaining intact remnant vegetation at very large spatial scales have proven challenging and elusive. Global land-cover maps derived from moderate- or coarse-resolution satellite imagery have existed since the early 1990s (Bontemps et al., 2011; Dong et al., 2012; Friedl et al., 2010; Loveland et al., 2000) but afford only broad nominal classifications of vegetation reflectance, structure, and phenology and do not therefore readily distinguish *disturbed* covers from natural, primary, intact covers *per se*, particularly in environments that are naturally unforested or

* Corresponding author. Tel.: +61 7 4042 1835; fax: +61 7 4042 1319.
E-mail address: sean.sloan@jcu.edu.au (S. Sloan).

http://dx.doi.org/10.1016/j.biocon.2014.05.027
0006-3207/

semi-forested, such as savannas. As illustrated below, an uncritical interpretation of such classifications in efforts to estimate the area of remaining natural intact vegetation is prone to significant error (Hoekstra et al., 2005). Global land-cover change analyses using satellite imagery are more promising insofar as they may exclude areas known to have undergone certain land-cover conversions (Hansen and DeFries, 2004; Hansen et al., 2013, 2008). Yet they remain similarly unable to address the integrity of supposedly 'unchanged' areas, which in a great many cases will be disturbed, and which in any case are observable at large spatial scales only at very coarse resolutions since the 1980s and at finer resolutions only since ca. 2000 with the advent of moderate-resolution imagery. While recent advances now provide relatively nuanced finer-scale measures of 'percent tree cover' and changes thereof since ca. 2000 (Hansen et al., 2003, 2013; Sexton et al., 2013), it has not been possible, nor will it likely be possible, to determine reliable thresholds identifying disturbed and thus undisturbed forest across large and varied regions, to say nothing of undisturbed vegetation in naturally semi-forested or unforested environments.

Two sets of relatively-derived estimates of remaining natural intact vegetation over large spatial scales have arisen in light of such issues. The first are those of Myers (1988, 1990), Myers et al. (2000), and Mittermeier et al. (1999, 2004), which entailed expert assessments of existing vegetation atlases, satellite-image classifications and similar secondary data for the hotspots. These estimates are now dated, difficult to replicate, and prone to inconsistency and approximation. The second set of estimates are those of Sanderson et al. (2002), Schmitt et al. (2009), Potapov et al. (2008), and Bryant et al. (1997), among others, which variously mapped intact areas with reference to criteria such as land-cover class, forest patch size, proximity to infrastructure, and accessibility. These estimates are problematic because they are either particular to closed-forest biomes, very large vegetation patches, or tree cover generally, or optimistically equate an absence of evidence of human disturbance with evidence of its absence. These are key limitations where habitats that are structurally and compositionally varied, heavily fragmented and under intense, proximate human pressure.

Updated and improved estimates of remaining natural intact vegetation (NIV) area in the hotspots are crucial for appropriate global conservation planning. Prior estimates have been used to prioritize hotspots for conservation action (Myers et al., 2000), determine their species-extinction susceptibility (Brooks et al., 2002; Malcolm et al., 2006), and calculate the costs their conservation (Pimm et al., 2001). In light of the uncertainties surrounding prior NIV estimates, such derivations are similarly subject to revision. A revision of hotspot conservation priority and attendant conservation action could have significant implications for future biodiversity loss and particularly its attenuation considering that biodiversity loss becomes increasingly exponential as the final vestiges of intact habitat are destroyed (Rybicki and Hanski, 2013; Turner, 1996). Rigorously updated NIV estimates for the hotspots are a matter of improved measurement for improved management.

Here we present updated, transparent, comprehensive and consistent estimates of NIV area and fragmentation for the world's biodiversity hotspots. The following section briefly reviews the hotspot concept and previous natural-area estimates. Section 3 discusses our methodology, and the subsequent sections present our estimates and highlight their implications for global conservation planning.

2. Hotspots and remaining natural vegetation

2.1. The hotspot approach and expert estimates

The hotspot concept prioritises the conservation of biologically-exceptional and highly-threatened regions with the explicit goal of stemming species extinction, as per the irreplaceability-vulnerability conservation framework articulated by Margules and Pressey (2000). Myers (1988) first encapsulated this concept globally by delimiting 10 largely tropical biogeographical regions of exceptional biodiversity and habitat destruction (Table 1) – the first 'hotspots', e.g., Madagascar, New Caledonia. Myers (1990) later added eight largely semi-arid hotspots to this list, e.g., Southwest Australia (Table 1). Conservation International adopted the hotspot concept as its central global conservation strategy in 1989 (Conservation International, 1990a,b; Mittermeier et al., 2004), and the concept has since become a major conceptual template among conservation scientists (Redford et al., 2003; Roberts et al., 2002; Sechrest et al., 2002; Turner et al., 2012; Willis et al., 2006). Myers, Conservation International, and collaborators later revised estimates of remaining primary habitat and defined the hotspots formally as biogeographic regions with >1500 endemic vascular plant species and $\leqslant$30% of original primary habitat (Mittermeier et al., 1999; Myers et al., 2000). Species endemism, rather than biodiversity *per se,* became a key definitional criterion given concern over extinction rates (Brooks et al., 2002; Mittermeier et al., 1998). This revision saw the hotspots expand in area as well as in number, to 25. A second global revision and update in 2004 (Mittermeier et al., 2004) expanded this count to 34 and adjusted hotspot boundaries to concord with the ecoregions of Olson et al. (2001). Recently, a 35th hotspot was added, the Forests of East Australia (Williams et al., 2011) (Fig. 1).

Mittermeier et al. (1999, 2004), Myers et al. (2000) and Myers (1988, 1990) present areal estimates of remaining natural intact habitat for the hotspots (Table 1). Their approach entailed first consulting estimates of vegetation cover and loss for those counties and/or regions within each hotspot, including vegetation atlases (e.g., Harcourt and Sayer, 1996), satellite forest-cover inventories (e.g., CCT/CIEDES, 1998), national environmental overviews (e.g., FWI/GFW, 2002), and occasionally the 1990 FAO Forest Resource Assessment (FAO, 1993). "Digitised forest cover data" from the World Conservation Monitoring Centre were also consulted (Mittermeier et al., 1998) (these data were uncited but are likely UNEP-WCMC (1996) or UNEP-WCMC (1998)). These estimates were then adjusted on the basis of expert opinion and unpublished data to estimate the area of "primary" or "more or less pristine" vegetation per hotspot (Mittermeier et al., 2004). Such adjustments sometimes reduced initial estimates by as much as 50%. Many of the source data were derived prior to the widespread use of GIS and satellite imagery at large scales, and no attempt was made to map primary vegetation in the hotspots.

The final estimates – hereafter termed *Expert Estimates* – while groundbreaking and widely adopted, are difficult to scrutinize and replicate. Expert adjustments of the initial estimates were not well documented and, in the absence of greater transparency, uncertainties tend to become generalized. The Expert Estimates derived from sources that were not necessarily comparable and occasionally had little explicit bearing on 'primary' versus 'perturbed' land covers. Further, many sources pertained to individual countries and it is unclear how these were adjusted to concord with the irregular biogeographic boundaries of hotspots (Fig. 1).

Perhaps more importantly, the Expert Estimates are increasingly dated. Even in the most recent update (Mittermeier et al., 2004) many of the data consulted span the 1980s and early 1990s, and habitat loss in the hotspots is certain to have advanced since (Balmford et al., 2002; Butchart et al., 2010; FAO, 2010; Hassan et al., 2005) as, among other drivers of habitat loss, increasing demand for agricultural products has been met in large part via continued habitat conversion (Gibbs et al., 2010; Laurance et al., 2014; Rudel et al., 2009). More recent global surveys of naturally vegetated areas have since been undertaken but, as argued below, these do not offer ready and reliable estimates for the hotspots.