TECHNICAL COMMENT

FOREST ECOLOGY

Comment on "The extent of forest in dryland biomes"

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The study by Bastin *et al*. (Reports, 12 May 2017, p. 635) is based on an incomplete delimitation of dry forest distribution and on an old and incorrect definition of drylands. Its sampling design includes many plots located in humid ecosystems and ignores critical areas for the conservation of dry forests. Therefore, its results and conclusions may be unreliable.

The recent Global Drylands Assessment of forests (*1*) clearly responds to a worldwide concern for better management and conservation of these ecosystems. Uncertainties about the contribution of these vast ecosystems (covering more than 40% of Earth's surface) to the global carbon balance, and about the value of their services, make these estimations necessary and timely. The presumed significant underestimates of forest cover presented by Bastin *et al.* (*1*) have implications for strategies of mitigation and adaptation to global warming. However, a careful analysis of their data and methodology reveals some drawbacks that limit the reach of these conclusions and their implications.

Bastin *et al.* claim that they use "the delineation adopted by the United Nations Environment Programme World Conservation Monitoring Centre [(UNEP-WCMC)]—lands having an aridity index (AI) lower than 0.65" (*1*, *2*). This affirmation is wrong. The delineation of UNEP-WCMC was based on the United Nations Convention to Combat Desertification (UNCCD)—i.e., the AI criterion—and on some additional ecoregions (*3*) or "relevant areas" from the point of view of the Convention on Biological Diversity (CBD). As Bastin *et al.* show [map in fig. S1 of (*1*), areas in dark gray], they ignored both zones "presumed included" and zones "to review" in the UNEP-WCMC proposal. Therefore, they are using the UNCCD criterion (i.e., AI < 0.65) and not the UNEP-WCMC delineation.

This choice has had two consequences. First, the "global dryland extent" considered was based on the UNEP Global Resource Information Database (GRID) (*4*, *5*) aridity zones data set. This is an old climatic database, with some errors, that induced Bastin *et al.* (*1*) to sample within non-dry areas. Even if they had desired to delineate drylands exclusively on the basis of AI, they should have used a corrected version (*6*) or, even better, they should have computed it by themselves. Computing AI on the basis of WorldClim, the standard global database used extensively by ecologists and biogeographers (*7*–*9*), shows that 10% of the plots evaluated by Bastin *et al.* (*1*), around 22,000 plots, were instead placed in areas with AI ≥ 0.65—non-dry areas according

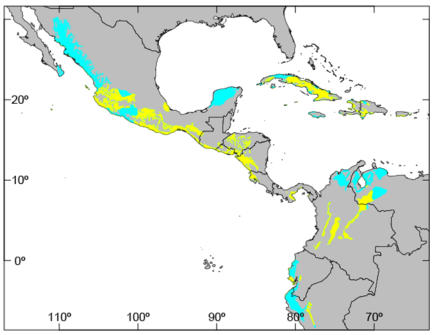

Fig. 1. Examples of omitted areas. Distribution of tropical and subtropical dry broadleaf seasonal forests in North America, Central America, and part of South America. Cyan areas are included in the original study. Yellow areas are omitted.

to UNCCD. These mistakes become apparent with a superficial inspection of the Global Drylands Assessment. For instance, most of the Ecuadorian easternmost rainforests (e.g., the Yasuní forest in the Napo region) and extensive parts of the southeastern Peruvian Amazonian forests were included as drylands. This error is also apparent when comparing the UNCCD aridity map (*2*) and its corrected version (*6*). This is a serious issue for the assessment of global dry forest cover because, for example, there are significant differences in tree cover between plots in non-dry (average 0.47) and genuine dry (average 0.11) locations (Kruskal-Wallis χ^2 = 15,233, df = 1, $P < 0.0001$).

There is a second caveat, a consequence of the drylands delimitation used: In addition to excluding the relevant areas for CBD, where some dry biomes could be found [some Mediterranean, desert, grassland, and savanna types (*2*)], the study also ignored the area occupied by the seasonal dry forests [i.e., the "tropical and subtropical dry broadleaf forests" biome (*3*)], which seems critical for the assessment of forest in drylands. The results of this exclusion are evident if the map of ecoregions (*3*) is overlaid on the map of dry areas used by Bastin *et al.* (*1*). At least 52% of the area considered by the World Wildlife Fund (WWF) as dry forest is not contained in the UNCCD delineation of drylands (*2*) and therefore is not considered by Bastin *et al.* (*1*). As a consequence, some critical dry regions were omitted (*10*, *11*). A simple comparison between them shows, for instance, the exclusion of extensive regions in Central America and Mexico (Fig. 1) and from most of the Asian southwest. On the contrary, the strict application of the erroneous AI map without further considerations resulted in some awkward facts, such as including 56% of world flooded grasslands, 10% of moist broadleaf forests, 23% of mangroves, and 51% of temperate forests as "dryland areas." In fact, placing the studied plots over the ecoregions map (*3*) shows that almost 35,000 plots (i.e., around 17%) fall within "non-dryland" biomes, including 11,887 plots located in moist forests (5.6%), 13,313 in temperate forests (6.2%), 5192 in taiga forests (2.4%), and even 362 plots in mangroves (Table 1).

Because any map will include errors, it is critical to understand their nature because they can propagate to other data sets (*12*, *13*). Bastin *et al.* (*1*) included an evaluation of the sampling and measurement errors attributable to estimation of forest area, but they did not make any attempt to validate the quality of the basal map used to define drylands (*2*). This could bring into question the validity of their results as a whole. A simple cross-tabulation of a sample of predicted classes against their corresponding observed classes would have been enough (*14*). Many measures can be derived from such a confusion matrix and used to test the validity of the work done. Bastin *et al.* (*1*) should have tested this before designing their sampling scheme and should have corrected it by excluding non-dry ecoregions and/or by recomputing the aridity index based on modern climatic databases. Other global assessments of the conservation status of dry forests (*15*) have taken these problems into consideration and have combined a corrected version of the aridity index (*6*) with the selection of ecoregions of interest (*3*).

Taking all these limitations into account, it is likely that the reported estimation of forest extent in dryland biomes, the 40 to 47% increase over previous estimates, and the potential 9% increase in the global area with >10% tree canopy cover suggested by the results of Bastin *et al.* (*1*) would be substantially different than claimed.

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Table 1. Distribution of plots identified as dry and non-dry biomes. Location of the 213,795 sampling plots among WWF terrestrial biomes and over a global map of aridity index (AI) computed on modern climatic databases. Each cell represents numbers of plots within each combination (biome × AI category). Two plots were not considered because of incomplete coordinates in the database, and there were no aridity index data for another 142 plots.

	Percentage of plots per biome	Aridity index (AI)	
		AI ≥ 0.65	AI < 0.65
Non-dry biomes			
Tropical and subtropical moist broadleaf forests	5.56	6,710	5,177
Tropical and subtropical coniferous forests	0.33	137	578
Temperate broadleaf and mixed forests	4.68	3,278	6,717
Temperate conifer forests	1.55	1,112	2,206
Boreal forests/taiga	2.43	3,529	1,663
Flooded grasslands and savannas	1.42	315	2,718
Tundra	0.12	254	2
Mangroves	0.17	202	160
Class 98 (inland water)	0.04	17	74
Class 99 (rock and ice)	0.01	27	0
Total	16.31	15,581	19,295
Dry biomes			
Tropical and subtropical dry broadleaf forests	3.25	1,297	5,649
Tropical and subtropical grasslands, savannas, and shrublands	25.45	2,175	52,197
Temperate grasslands, savannas, and shrublands	11.62	1,152	23,676
Montane grasslands and shrublands	2.59	508	5,019
Mediterranean forests, woodlands, and scrub	4.66	306	9,644
Deserts and xeric shrublands	36.11	502	76,650
Total	83.68	5,940	172,835

This limits the usefulness of the implications of their results in developing and reconsidering strategies of mitigation and adaptation to global warming at a global scale.

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