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COMMENTARY

Where are the Subtropics?

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ABSTRACT

The tropics are clearly defined while 'subtropics' and 'subtropical' have been applied to a variety of zones, climates, and ecosystems. However, in the recent terrestrial biology literature, they have been used mainly for the zones between the tropics (±23.4°C) and ±30.0°. Adopting this standard would facilitate pan-subtropical comparisons.

Key words: climate; frost; latitude; subtropical; tropics.

THE TROPICS (±23.4°) ARE CLEARLY DEFINED BY THE OVERHEAD SUN, although 'tropical' climates, vegetation, and species may extend beyond these limits, or be absent within them. From a biological perspective, this is an arbitrary definition, but its universal acceptance has made possible the explosive development of tropical biology over recent decades. International journals and conferences about the tropics, and intercontinental comparisons, all depend on an agreed definition of what it is we are studying. Numerous authors have tried to define the tropics in a less arbitrary way (*e.g.*, Köppen, von Wissman, Troll & Paffen, Lauer & Frankenberg, Flohn, and Huang, all in Domroes [2003], Trewartha 1968, Holdridge 1978), using climatic features, usually chosen for their correlation with the distribution of important crops or major vegetation types. None of these bioclimatic definitions has achieved wide acceptance, however, because there are so many defendable ways of doing it (*e.g.*, multiple possible values of absolute minimum temperature, mean temperature of the coldest month, heat sum, mean annual biotemperature, or a greater diurnal than annual temperature range). The biologically arbitrary 'solar' definition also removes the problem of the altitudinal boundary of the tropics that arises with temperature-based definitions, except those based on seasonality (Domroes 2003).

The subtropics, in contrast, although almost universally recognized, have no widely agreed definition and—I would argue as a partial consequence—no journals, conferences, or intercontinental comparisons, despite the large area these zones cover in many big countries (including China, India, Mexico, Argentina, South Africa, and Australia). Although an etymological case could be made for defining the subtropics as a subdivision of the tropics, the term is now typically used to describe the regions outside, but bordering, the tropics. The main disagreement is with the poleward limits. Physical geographers tend to set broad limits, extending to 35° or 40°, or define the limits climatically (*e.g.,* Petersen *et al.* 2010, Marsh & Kaufman 2012). In the widely used Köppen (or Köppen-Geiger) climate classification (Peel *et al.* 2007), subtropical climates extend to 45°N in some places, although more recent modifications of this scheme have tended to remove the colder half of this broad belt. Griffiths (1976) used a coldest month mean of 6°C, rather than Köppen-Geiger's −3°C, as the northern limit of the subtropics, whereas Trewartha (1968) used 8 mo above 10°C. Köppen excluded arid climates from his definition of the subtropics, dividing these only into hot and cold types, whereas Griffiths used the same temperature scale as the other climates. Holdridge (1978) used equal logarithmic divisions of the mean annual biotemperature (the mean with all temperatures <0°C adjusted to 0°C and >30°C adjusted to 30°C) as the primary axis in his classification into 'life zones', but split the 12–24°C zone into two (subtropical and warm temperate) at the frost line. As a result, most of the area of 'subtropical' life zones lies within the solar tropics.

As with the tropics, the number of possible climatic or ecological definitions of the subtropics is unlimited and there is no mechanism to ensure universal agreement, so this path guarantees continued confusion. Do we exclude arid climates, as Köppen did, or do we allow 'subtropical deserts' as the modern literature does? Do we set the northern limit at a coldest month mean of −3°C, 0°C, or 6°C, all of which have been plausibly advocated, or use some other temperature parameter? How do we deal with topographic effects on climate? Moreover, with the lower latitudinal limits of the subtropics effectively fixed by the solar definition of the tropics, a climatic definition of the subtropics risks gaps or overlaps between our usages of the terms tropics and subtropics that would only add to the confusion. For most practical purposes, therefore, defining the subtropics as a fixed latitudinal belt, as we do for the tropics, makes more sense. Most importantly, this would facilitate pan-subtropical comparisons in ecology and other environmental fields, which currently appear to be rare compared with pantropical comparisons.

Rather than attempt to redefine a widely used term, I have instead assessed how it is currently used by terrestrial ecologists and other tropical terrestrial biologists to see if there

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is any hope of standardization. I excluded marine systems because of the rather different zonation imposed by physical oceanography. I searched for articles published in English since 2000 that used the terms subtropics or (more commonly) subtropical in the title. Initially, I confined the search to major international journals in ecology (*Ecology*, *Journal of Ecology*, *Oecologia*, *Plant Ecology*), tropical ecology (*Biotropica*, *Journal of Tropical Ecology*), biology (*American Journal of Botany*, *Journal of Zoology*), forestry (*Forest Ecology & Management*), and conservation biology (*Conservation Biology, Biological Conservation, Biodiversity & Conservation*), but I had to include some papers from lower ranked journals (all international and without a specific geographical focus) for areas of the world that were inadequately represented (<10) in the initial survey. From each article, I extracted the latitude of the main study site. Where a range of latitudes was given, I took the mean, as I also did for multiple nearby sites, but I excluded all articles where the latitudinal spread of sites was large (>1°) or where there was any ambiguity in the designation of the site as subtropical.

I found 180 articles from 14 countries that met my criteria: 92 from Asia (mostly China, followed by Japan and India), 34 from South America (mostly Argentina and Brazil), 18 from Australia, 13 from the Caribbean (mostly Puerto Rico), 11 from North America, 10 from South Africa, and 2 from the Canary Islands. Only 18 articles (10%) used subtropical to refer to a site poleward of 30.0°, and all these were at 30.0–33.0° and referred to ecosystems that occurred predominantly below 30.0°. A total of 26 articles (14%) applied the term subtropical to sites within the tropics, but half of these were in the Caribbean (18.0–19.1°; all but one in Puerto Rico), three others were also in the Neotropics (19.8–20.9°), and all the rest were poleward of 22.0°. Except for the Caribbean, a majority of sites in all regions were in the latitudinal belts 23.4–30.0° from the equator. The overall median was 26.7° and the range of medians across regions with >10 articles and land spanning this belt was 26.1° (South America) to 28.8° (South Africa). Reanalysis using sites (N = 133) rather than articles (N = 180) as replicates had a negligible effect on these numbers.

Thus, current usage across the subtropics largely (75.6% of recent articles studied) restricts this term to the latitudinal belts poleward from the Tropics of Cancer and Capricorn to 30.0° north and south. This agreement was surprising as I came across no explicit definition of the subtropics that used these limits. The significant exceptions (>3°) were all on the equatorward side and all reflect the life zone system of Holdridge (1978), which has been widely used in the Neotropics, but rarely elsewhere. The occurrence in this system of 'subtropical' life zones well within the tropics seems to be a simple consequence of the use of equal logarithmic divisions of the mean annual biotemperature, rather than a reflection of any fundamental biological change at the threshold biotemperature of 24°C.

How coherent are the subtropics if defined as the latitudinal belts between 23.4° and 30.0° N/S? These two belts are separated by the 5185-km width of the tropics, but this is no more than the distance that separates some major tropical land areas (Corlett & Primack 2006). Tropical montane habitats may have acted as bridges or stepping stones across the tropical lowlands, most obviously in South America. Where mountains are absent or marine barriers occur, vertebrate faunas at similar longitudes can be very different—only the most mobile groups are shared between humid subtropical Asia and Australia, for example—but floras and invertebrates faunas are more similar. The explosive speciation of the plant genus *Ilex* in both (northern) subtropical East Asia and (southern) subtropical South America, and its presence in most other subtropical humid forests, is an example of this latter pattern. As with the tropics, these similarities and differences provide opportunities for intercontinental comparisons that treat widely separated areas as 'natural experiments' in the assembly of subtropical biotas.

As one moves away from the border of the tropics, winter low temperatures decline, mild frosts become more frequent, and tropical plant taxa are increasingly excluded. It is tempting, therefore, to see the subtropics as merely transition zones between tropical and temperate systems. This view, however, is at least partly an artifact of the common and arbitrary division of taxa into two—tropical and non-tropical—and the pattern would look different if taxa that occurred predominantly between 23.4° and 30.0° N/S were placed in a separate category. In East Asia, where the land area declines toward the equator, some higher level taxa reach maximum diversity in the subtropics (*e.g.,* breeding birds; Ding *et al.* 2006). In any case, climate gradients in the subtropics are no steeper than in other extratropical regions.

Ecologically, the natural vegetation of humid subtropical regions is a distinctive type of evergreen broad-leaved forest, recognized in most regional vegetation classifications and with a similar structure in all regions (pers. obs.). At least in East Asia, these forests maintain high rates of photosynthetic activity yearround (Tan *et al.* 2012), unlike forests further polewards. Arid and semi-arid ecosystems in this belt vary greatly between regions in their floristics, but await a global comparison of their structure and function.

I conclude that we should restrict the use of the term 'subtropics' to the latitudinal belt between 23.4° and 30.0°, at least in titles, abstracts, keywords, and global comparisons. The choice of 30.0° is arbitrary, but convenient and already conventional. As with the term 'tropical', it would be reasonable to allow the use of the adjectival 'subtropical' to refer to climates, ecosystems, or species that occur predominantly within the subtropics, but may extend a few degrees above or below this belt. Where widely used regional vegetation or climate classification systems, such as those of Holdridge and Köppen-Geiger discussed above, incorporate a different usage of the term subtropical, an explicit distinction should be made in the text between the vegetation or climate type and the latitudinal belt.

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