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A concise scheme of vegetation boundary terms in subtropical high mountains

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There are numerous terms used to describe the vegetation boundary in high mountains. It is essential to define and agree on a unified usage for these terms. The literature review method had been used in this paper to clarify the vegetation boundary terms and their scopes. The result revealed that these terms were much diversified and ambiguous, and more or less related and infringed with each other in ecological concept and visible landscape, even mutually used as synonyms in some cases. We proposed a concise scheme for clarifying these terms and illustrating their relationship, including timberline [instead of previously used economic (rational, generative) forest-line, economic timberline, limit of continuous forest], forestline [instead of physiognomic (empirical, vegetative, biologic) forest-line, actual timberline, physiognomic forest-limit], treeline (instead of tree limit and treeline), krummholzline (instead of tree-species line, tree species limit, krummholz limit), and historic treeline. The 5 boundary terms could facilitate the comprehension of spatial sequence of vegetation transformation in high mountains. However, all boundaries do not necessarily occur in all mountains of the world concurrently. In some papers, the term timberline or treeline once referred to the ecotone from continuous forest to tree less landscape, but the term forest–tundra ecotone should obtain more commendations when vegetation transition is much more gradual particularly around the subarctic. To avoid the confusion from using these boundary terms, we suggest that authors studying boundary related issues should interpret their scope of terminologies and provide the basic description about environment and vegetation outlines in the complex high mountains.

Key words: Timberline, forestline, treeline, krummholzline, high mountains.

INTRODUCTION

There are mainly four vegetation types in high mountains, including closed-canopy forest, open-canopy forest, krummholz, and treeless tundra. The boundaries among them, usually called treeline or timberline etc., are the most conspicuous vegetation boundaries (Holtmeier and Broll, 2010; Hoch and Körner, 2012). In recent years, the

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treeline related issues have been increasingly discussed due to concern over the effects of climatic change (Holtmeier, 1985, 2009; Holtmeier and Broll, 2005, 2007; Timoney et al., 1992), as the boundary between forest and tundra may be a sensitive indicator or bellwether of response to global warming (Kullman, 2001; Smith et al., 2009). Some authors considered that boundaries may serve as indicators only under certain circumstances (Risser, 1995; Slayter and Noble, 1992), but undoubtedly, it is an interesting and important issue in ecology and landscape.

Terms and concepts crucial to understanding ecology have often been criticized for their tautological, equivocal or nonoperational nature (Colautti and MacIsaac, 2004). The tree line related terms are numerous and rather ambiguous due to the great ecological, physiognomic, and taxonomic varieties and the multidisciplinary and multilingual nature of the subject matter (Autio, 2006). It is often unclear or unstated, moreover, what criteria to define these terms. Differences in terminology and definition itself lead to miscommunication and may make direct comparisons difficult among areas studied by different authors (Timoney et al., 1992). When using the treeline as criterion for assessing effects of climate change, for example, we cannot validate whether the worldwide treeline in different reports (such as 10 different tree line positions in Walther et al., 2005) is consistent. Also, it is insecure to compare the positions of alpine vegetation boundaries indifferent papers whose references used several different boundary terms (Crausbay and Hotchkiss, 2010; Körner, 1998; Körner and Paulsen, 2004; Tuhkanen, 1993). Thus, clarifying the treeline, related terms is fundamental for studying high-mountain issues. The aims of this paper are to review the treeline related terms and their scopes, and to recommend several concise terms to integrate various and ambiguous terms regarding the boundaries and ecological zones, and to illustrate the relationship between different terms as fundamental work for future research.

MATERIALS AND METHODS

The literature review method was used in this paper for clarifying the tree line related terms and their scopes. Thomson Institute for Scientific Information (ISI; http://apps.webofknowledge.com/) and Google Scholar (GS; http://scholar.google.com/) were used to search tree line related terms. ISI is today's premier research platform for information in the sciences and commonly used as source of bibliometric data; and GS database provides broader data not only from the strict ISI criteria, but also from conference proceedings, working papers, and books (Schiederig et al., 2012).

For the literature review and analysis, a bibliometric search from the scientific and popular literatures in ISI and GS had been performed (Harzing and Wal, 2008). Publications were collected using the search strings 'tree line', 'forest line', and 'timber line' as well as all their variants. Then, the content with respect to definition, scope, and scheme of these tree line related terms have been analyzed further.

RESULTS AND DISCUSSION

Historic usage of boundary terms

Table 1 is the number of publications of tree line related terms through search in ISI database and GS database. The total number of publications is 2,652 in ISI searching by topic, 1,394 in GS searching by topic, and 83,965 in GS searching by all. The result of "search by topic" in ISI reveals that 1,757 (66.63%) publications apply the notion 'tree line' and all its variants, 678 (25.56%) for 'timber line', 203 (7.65%) for 'forest-line', 2 (0.08%) for 'historical tree line', and 2 (0.08%) for 'tree-species line'. For "search by topic" in GS, a search for 'tree line' retrieves 860 (61.69%) items, for 'timber line' 426 (30.56%) items, for 'forest-line' 106 (4.61%) items, for 'historical tree line' 2 (0.14%) items, and for 'tree-species line' 0 (0.00%) items. These results reveal that treeline is the most common used term for representing the boundary line and timberline is the second common term. When the suggestion "search by topic" in GS by Webster and Watson (2002) adopted, the string 'tree-species line' or 'historical tree line' had no result. They are in frequently used terms.

Historically, many terms were used to name the boundaries between two adjacent plant communities in high mountains, mainly including 5 different kinds of lines (Tables 1 and 2). Many authors, such as Hustich (1979), Payette (1983), Tuhkanen (1993), Scott (1997), Körner and Paulsen (2004), Autio (2006), Holtmeier and Broll (2010) and Harsch and Bader (2011) once illustrated their schemes regarding these terms. An earlier scheme of boundary terms had been proposed by Hustich (1979). The schematic succession of boundary terms was similar reported by Scott (1997), as appeared in Table 2, he stated "Alpine environments are here described as those that exist above timberline, a rather rich concept in itself as five different kinds of timberline are listed: economic forest line (above which trees cannot be economically harvested), forest limit (physiognomic forest line), tree limit (some species reach tree size), tree species limit (tree species are stunted but present, that is, krummholz, elfinwood or krupelkiefer), and historic tree line (indicating earlier climatic regimes)."

These boundary terms sometimes had their substitute spelling or variant and occasionally used interchangeably or as synonyms in appropriately (Tables 2 and 3). A veritable "Babel of nomenclatures" of the boundary related terminology did exist (Hare and Ritchie, 1972). In fact, these terms can complement or conflict with each other, more or less related and infringed in the ecological concept and in the visible landscape (Armand, 1992; Hustich, 1979; Körner and Paulsen, 2004). Although, there have been many attempts for clarifying these terms (Holtmeier, 2009; Hustich, 1983), none have proved satisfactory, and the generally accepted classification scheme is far from complete (Autio, 2006).

Table 1. Total number of items in Institute for Scientific Information (ISI) and Google Scholar (GS) database for five boundary terms and their synonyms and variants.

Term	Items in ISI (search by topic)	Items in GS (search by topic)	Items in GS (search by all)
Historical tree-line*	2	0	14
Historical treeline	0	2	17
Historical tree-limit	0	0	2
Historical treelimit	0	0	0
Historic tree-line	0	0	6
Historic treeline	0	0	5
Post-glacial tree line	0	0	1
Subtotal	2	2	45
Tree-species line	1	0	60
Tree-species limit	0	0	52
Krummholz-line	0	0	14
Krummholzline	0	0	0
Krummholz-limit	1	0	32
Krummholzlimit	0	0	0
Subtotal	2	0	158
Tree-line	755	251	29,400
Treeline	893	542	19,100
Tree-limit	119	67	3,270
Treelimit	0	0	54
Subtotal	1,767	860	51,824
Forest-line	87	40	2,780
Forestline	3	3	94
Forest-limit	113	63	2,550
Forestlimit	0	0	2
Subtotal	203	106	5,426
Timber-line	39	35	6,700
Timberline	639	391	19,600
Timber-limit	0	0	211
Timberlimit	0	0	1
Subtotal	678	426	26,512
Forest–tundra ecotone	106	119	1,650
Tree-line ecotone	26	9	227
Treeline ecotone	84	60	1,010
Forest-line ecotone	3	1	33
Forestline ecotone	0	0	1
Timber-line ecotone	0	2	52
Timberline ecotone	35	56	586
Subtotal	254	247	3,559

* The search string ‘tree-line’ and ‘treeline’, also as other terms, are synonyms (dash = space).

Concepts of the transitions of high-mountain environment and vegetation

Environmental conditions become progressively harsher with an increase in altitude due to a decrease in temperature as well as increases in wind-speed, snow cover and other severe factors related to the survival, growth, and regeneration of plant (Körner, 2003; Schickhoff, 2005; Sveinbjörnsson, 2000). The increasingly severe environment gradually affects the transition of flora and physiognomy (Bader et al., 2007; Holtmeier, 2009). The transition from the closed mountain forests to treeless alpine vegetation is commonly a gradient of increasing stand fragmentation and stuntedness (Körner and Paulsen, 2004), as gradually opening canopy and declining tree size.

Table 2. Examples of different definition or expression regarding high-mountain boundary terms.

Terms	Definition or expression of boundary terms (their synonyms and variants marked in italic)*
Historic treeline	Beyond and above the tree species line there are to be found numerous remnants of trees that grew at those sites when the climate was warmer than nowadays, and the outermost occurrences of these constitute the historical tree line, generally understood as the highest post-glacial tree line (Heikkinen, 2005). Determined by the location of subfossil trees, that is, ancient, dead trees that remain well preserved (Kharuk et al., 2009)
Krummholzline	A subalpine transitional zone or krummholz line characterized by increasingly stunted and dwarfed trees is the norm in circumpolar and northern temperate zone mountains (Sarmiento and Frolich, 2002). Tree species limit or krummholz limit: the uppermost limit of isolated and small individuals (Finsinger and Tinner, 2007)
Treeline	I will use the term treeline in a general sense to refer to the transition from forests to treeless vegetation (Tuhkanen, 1993). We use the term treeline to denote the actual upper boundary of contiguous closed-canopy forest, irrespective of whether or not this represents the potential climatic upper limit for tree growth (Bader et al., 2007).
Forestline	physiognomic forest line: limit of vegetatively reproducing trees (Johnson and Miyanishi, 1999) Actual timberline is a generic term denoting to continuous, altitudinal mountain timberline. This line has also been called an empirical forest line/timberline, and physiognomic forest line. Areas above the actual timberline are characterised by smaller trees, which grow in groups or alone (Autio and Eolpaert, 2005).
Timberline	The term timberline has been variously used. It may refer to the economic forest line or even to treeline proper (Tuhkanen, 1993). Timberline or forest limit: maximum elevation of forest with cover of at least 30~40% given by arboreal individuals >5 m high (Batllori et al., 2009).

* There is more or less disagreement in the connotation and domain of these terms.

At a global scale, natural vegetation transitions along altitude are controlled primarily by climate (Tuhkanen, 1993) mainly caused by heat deficiency (Holtmeier and Broll, 2010), that is, insufficient temperature and growing season length (Holtmeier, 2009; Hustich, 1979; Schickhoff, 2005). The altitudinal and thermal gradient directs the pattern of vegetation transition, but local climate, topography, site history, ecology of plant species, current biotic and anthropogenic influences (Bader, 2007; Holtmeier, 1985, 2009; Schickhoff, 2005; Wardle, 1971) greatly modify this pattern in different ways (Camarero and Gutiérrez, 2001). Thus, the patterns of transitional vegetation in high mountains include wide ecotone, mosaic of patch, and abrupt boundary (Arno and Hammerly, 1984; Bader et al., 2007; Holtmeier, 1985, 2009; Körner, 2003).

Also, Norton and Schönenberger (1984) once illustrated four transitional types how forest is replaced by alpine vegetation, including: (1) abrupt forest limit bordering alpine vegetation, (2) transition zone (ecotone), (3) true krummholz belt above the upright growing forest, and (4) gradual transition from high-stemmed forest to crippled trees of the same species bordering alpine vegetation. Harsch and Bader (2011) illustrated conceptual diagram of four tree line forms, diffuse, abrupt, islands, and krummholz showed the zone between the upper and lower end varied greatly in width and character. Generally speaking, the vegetation transition is sharper near a boundary or more gradual close to an ecotone (Holtmeier, 2009; Körner, 2003; Payette, 1983; Schickhoff, 2005).

Is the transition between two adjacent communities a line or an ecotone? It is difficult to answer this question conclusively. An explanation had once been made by Armand (1992): “Any natural boundary is in reality a transition zone, which has its own two boundaries. They are, in turn, also transition zones with their own boundaries, and so on endlessly. So localization of a natural border is in principle inexact and therefore determined by convention.” Moreover, the transitional gradient and spread of vegetation are dissimilar in different parts of the world. For example, the actual transition for Nothofagus in the Southern Hemisphere often forms a sharp boundary at its upper limit (Fajardo and McIntire, 2012; Wardle, 1971, 1998); whereas around the subarctic, the breadth of the forest-tundra transition zone is rather wide and indistinct, often exceeding 40 km and even over 200 km (Virtanen et al., 2004).

In some mountains, the transition zone is not abrupt, such as Pinus albicaulis in Montana alpine, which is called as diffuse tree line (Fajardo and McIntire, 2012; Harsch and Bader, 2011). Consequently, sometimes the vegetation boundary was seen as a line or sometimes as a synonym of an ecotone despite the zonal width (Young and León, 2007).

A natural boundary receives discordant identifications in relationship to observation scale and transition zone width (Bader et al., 2007). Most people would intuitively agree about the position of the boundary when it is

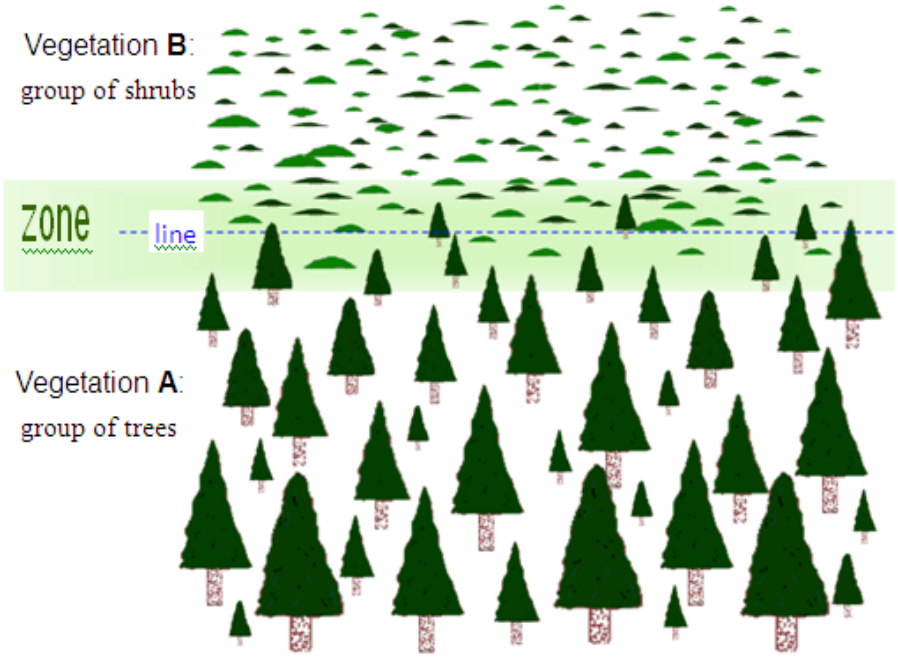

Figure 1. The presentation of vegetation or life-form transition from A (group of trees) to B (group of shrubs) could be considered as two representative types, a sharp line or a gradual zone of varying width, depending on the observation scale, the width of transition zone, and the characteristic of species (genetically-predetermined vs. environmentally-induced forms).

viewed from an airplane at great distance, but would strongly disagree when faced with the local situation on the ground (Körner, 1998). Holtmeier (2009) once said that “Timberline is a biological boundary, a more or less wide ecotone.” to metaphorically contain both lineal and zonal concepts within tree-line related term itself. As Figure 1 illustrates, we could consider vegetation below the boundary to be A (group of trees) whereas vegetation above the boundary is B (group of shrubs), that is, the boundary is where A ends and B begins. Figure 2 shows some cases in Mt. Shei (its peak 3884 m asl) of Taiwan: Figure 2a and b as vegetation A; Figure 2c and d as vegetation B; and Figure 2e and f show the boundary between vegetation A and B. When the transition from A to B is narrow and sharp, the vegetation boundary is considered as a line. In contrast with this line, the vegetation boundary is considered as a transition zone or an ecotone when the transition from A to B is wide and gradual. Thus, in essence, the high-mountain vegetation boundary between closed forest and treeless area is a line or a transition zone (Holtmeier and Broll, 2005, 2010) often determined by convention (Armand, 1992; Körner and Paulsen, 2004). At coarse scales, the terms alpine tree-line ecotone and forest–tundra ecotone were often used to represent the transition from forest to tundra. On the other hand, when we considered that the transition zone or ecotone was a boundary, the vegetation zones separated by the boundary will form more uniform physiognomy, such as forest and krummholz (or tundra).

Concise terms and scheme of boundaries

In this paper, the concise terms regarding these boundaries from lower to higher elevation and their general definitions had been suggested as follows and illustrated in Figure 3. The reasons of this concise scheme and terms to replace others had been interpreted in the following subsection:

1) Timberline is the uppermost elevational limit of continuous closed forest. It represents the topmost boundary of forest with larger trees and more closed canopy.
2) Forestline is the uppermost elevational limit of open forest. It represents the topmost boundary of forest with smaller trees and opener canopy.
3) Treeline is the uppermost elevational limit of individual trees. It represents the topmost boundary of at least 2 m height and scattered trees.
4) Krummholzline is the uppermost elevational limit of shrubby, stunted or mat-form woody plants. The krummholz can be divided into genetically-predetermined krummholz (genotype) and environmentally-induced

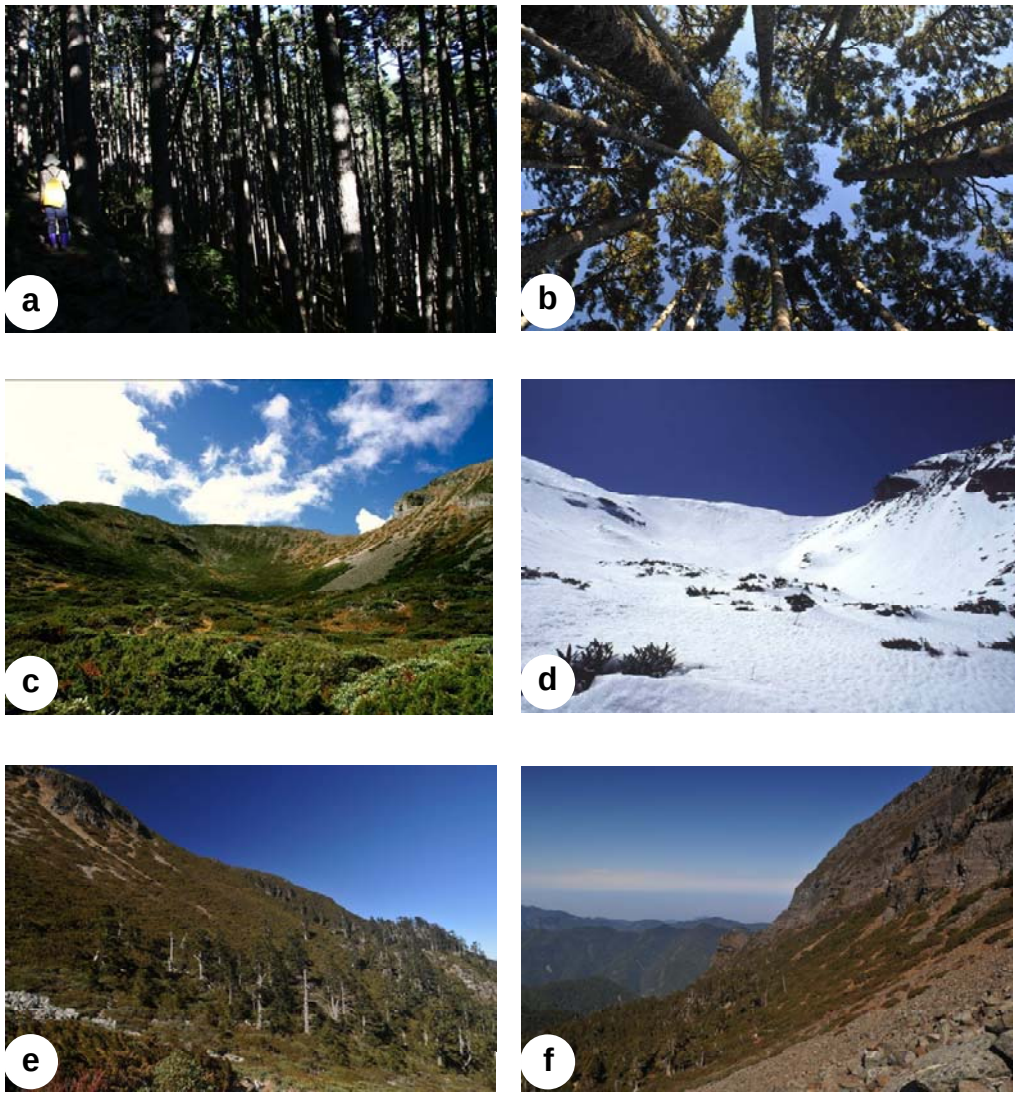

Figure 2. (a)*Abies kawakamii*, its growth form only upright tree, comprises the closed-forest (at the east slope of Mt. Shei, ca. 3,375 m asl). (b) The canopy of closed-forest is more than 60% where tree crowns usually interlocking. (c) The summer scenery at the semi-circular glacial cirque formed during the last glaciation, the *krummholz* (at the east slope of Mt.Shei, above ca. 3,650 m asl) is mainly composed of the shrubs *Juniperus squamata* var. *morrisonicola* and *Rhododendron pseudochrysanthum*. (d) The winter scenery as the same view of photo c, the *krummholz* is shaped principally from strong wind, gravel, winter snowpack, and insufficient air and soil temperatures. (e) At the east slope of Mt. Shei, there is no significant tree line. The fingered forest line where *Abies* forest ends and *krummholz* begins occurs at ca. 3,600 m asl. (f) At the west slope of Mt. Shei, the transition from forest to scrub is sharper than on photo e. The forest-line where *Juniperus* forest ends and *krummholz* begins occurs at ca. 3,700 m asl. (Photos a and b by Chun-Min Wang in 2010; c and d by Ching-Chi Hsu in 2004, 2005; e and f by Ching-An Chiu in 2008 and 2010).

krummholz (phenotype) (Holtmeier, 1981, 2009).
5) Historic treeline is the uppermost elevational limit of the trees during Hypsithermal period, identified from paleoecological subfossil evidence. The subfossil trees exist, that is, the ancient and dead trees remain well preserved.

Of various criteria used to delimit the boundaries in high mountains, emphases have been placed on the height, stem density, and growth form of woody plants (Holtmeier, 2009; Timoney et al., 1992). For clarifying the difference among these terms, two questions must be answered: What is a tree? What is a forest? As Lund (2009) had shown, there were 199 definitions of the term tree in use throughout the world. A tree is defined as an upright woody plant with a dominant above-ground stem

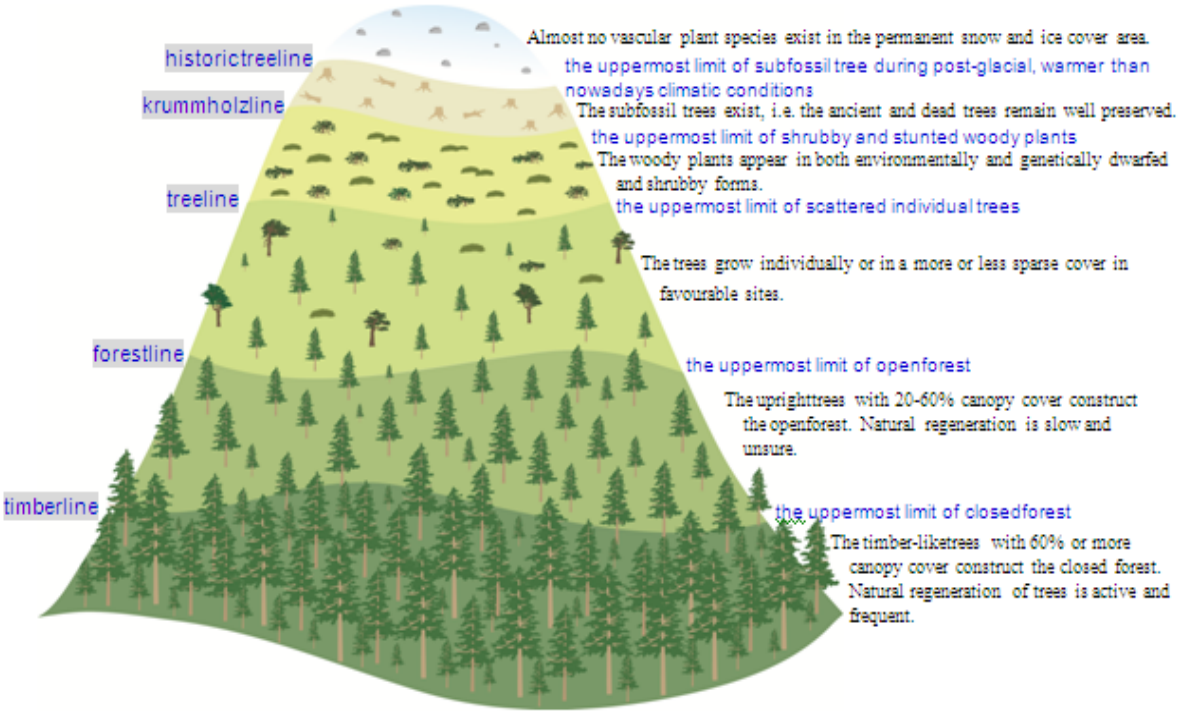

Figure 3. A concise schematic diagram designed to explain the transitional gradients and their boundaries among high-mountain ecosystems: ideas and concepts adopted from Hustich (1953, 1979), Payette (1983), Tuhkanen (1993), Sveinbjörnsson (2000), Körner and Paulsen (2004), Autio (2006), Holtmeier (2009), and Harsch and Bader (2011), but more concise and more intuitive. These concise terms timber line, forest line, tree line, krummholz line, and historic tree line (in blue words) are ordered in sequence by increasing altitude ideally.

with a minimum height from 1 to 8 m (Autio, 2006; Holtmeier, 2009; Hustich, 1979). Trees are also described as timber-sized (Wardle, 1965), or as any individual with one or more stems 10 cm diameter at 50 cm above the forest floor (Cullen et al., 2001). In this paper, we prefer that a tree is defined as an upright woody plant with an erect stem which reaches a height of at least 2 m, independently of whether reproduction occurs or not (Körner, 1998) and multi-stemmed or not. The definition using a critical trunk height makes it rather straight forward to distinguish trees from shrubs.

Furthermore, a forest is loosely understood as an area with a high density of trees or a biological community dominated by trees. There are more than 950 definitions of the term forest (Helms, 2002; Lund, 2009), based on the various criteria. We recommend that a forest is an ecosystem dominated by trees with a total canopy cover of 20% or more. Based on the critical canopy cover by referring to international vegetation classification (Grossman et al., 1998), the area is considered as openforest if the tree cover is between 20 and 60% and as closedforest if the tree cover is more than 60% where tree crowns usually interlocking.

First and foremost, we had better make sure the difference between timberline and forestline. The term timberline seems clear enough in semantics and is “the upper limit of tall, erect timber-sized trees (Wardle, 1965)” to represent the uppermost elevational limit of closedforest. As revealed in Table 2, the more brief term timberline can replace the limit of continuous forest (Payette, 1983), the economic limit of forest (Hustich, 1953), or the economical, rational, and generative forest-line (Hustich, 1979; Scott, 1997; Tuhkanen, 1993). It can also replace the economic timber-line (Autio, 2006; Holtmeier, 2009). Tree regeneration is active and timber harvesting is possible below the timberline, whereas natural regeneration of tree is slower and uncertain above the timberline. In contrast with timberline, we propose to use the term forestline to represent the uppermost elevational limit of open forest. As revealed in Table 2, the more brief term forestline can replace the physiognomic forest-limit (Payette, 1983), biological limit of forest (Hustich, 1953), physiognomic (biologic) forest line (Tuhkanen, 1993), forest limit (Scott, 1997), empirical timberline (Dahl, 1998), actual timberline (Autio and Colpaert, 2005; Autio, 2006; Holtmeier, 2009), or physiognomic (empirical, vegetative) forest-line (Hustich, 1979).

Although, treeline was defined as the connection between the highest elevation groups of trees, and Körner and Paulsen (2004) proposed that such a definition was a convention for communication and did

not deserve a major scientific debate. We suggested that it is necessary to separate treeline from other terms such as timberline and forestline or from treeline ecotone (Körner, 1998, also discussed in the next section). Here we defined the term treeline as the uppermost elevational limit of scattered individual trees, giving up the different writing forms such as treeline and tree limit (Autio, 2006; Scott, 1997) for the sake of uniformity in our scheme. Note that this definition ignored certain circumstances, such as isolated tree outposts or tree islands [trees occurring above the treeline in the more preferable microhabitat as described by Holtmeier and Broll (1992).

Above the treeline, woody plants still occur and are often much shorter and more crooked than those at lower elevations. Their twisted and deformed physiognomies are genetically predetermined or shaped by climatic influences (Holtmeier, 1981). These shrubs are often known as krummholz, and both are genetically and phenotypically determined (Holtmeier, 2009); Such krummholz scrubs may be composed of both living and dead stems, and branches several hundred years old (Payette et al., 2008) but still be a stunted dwarf (Holtmeier, 1981, 2009). We defined the term krummholz line as the uppermost elevational limit of shrubby, stunted or mat-form woody plants, that is, the beginning of the treeless alpine zone (Körner, 1998). It is often referred to as the tree species limit (Payette, 1983; Scott, 1997), tree-species line (Autio, 2006; Hustich, 1979; Tuhkanen, 1993), tree species line (Körner and Paulsen, 2004), species line (Sveinbjörnsson, 2000), or krummholz limit (Finsinger and Tinner, 2007) (also see Table 2). But their positions of tree-species line and krummholz line are different, particularly in some alpine beyond the krummholz line where creeping willow and woody cushion plants occur. Sometimes, the term historic treeline was identified beyond the krummholz line based on macrofossils and other evidence (Holtmeier, 2009; Hustich, 1983) that existed during post-glacial, warmer than nowadays climatic conditions, but it had never been reported in tropical high mountains.

Tables 2 and 3 list some examples of boundary terms. They reveal that there are spelling differences or synonyms in custom, usage, or opinion by different authors. A bibliometric search using these various terms (including all their synonyms and variants, Table 3) in GS shows their counts of scholarly publications and citations (Harzing and Wal, 2008). The term treeline, a total of 51,824 items in GS is the most familiar usage, and timberline is the secondary one (26,512 items in GS); indeed, they are often rather ambiguous and may be inter-invasive or interchangeable in different papers. Thus, we proposed to clear the 5 different boundaries and give the more concise terms and the identical writing form. Figure 3 illustrated a schematic diagram designed to concisely explain the vegetation transition and their boundaries in high mountains physically. These concise terms timberline, forestline, treeline, krummholzline, and historic treeline are ordered in sequence by increasing altitude. The primary ideas and concepts are adopted from Hustich (1953, 1979), Payette (1983), Tuhkanen (1993), Sveinbjörnsson (2000), Körner and Paulsen (2004), Autio (2006), Holtmeier (2009), Harsch and Bader (2011), but more concise and more intuitive.

Termsto replace “ecotone”

Various biotic and abiotic factors and processes result in the manifold patterns of vegetation transition in different regions. The boundaries mentioned above are sometimes regarded as a transition zone (Armand, 1992), an ecotone (Holtmeier, 2009), or as an area of ecological tension over which one type of vegetation is gradually replaced by another (Walter, 1985). In other words, the upper elevational limit of forest and tree growth and survival on high mountains, defined as a line is included within this ecotone (Batllori et al., 2009; Holtmeier, 2009) (Figure 1).

The terms timberline and treeline were often used to refer to ecotone from closed continuous forest to treeless alpine, such as: (1) Leuschner (1996) noted “The term timberline as used here includes forest line and tree line.” Wieser and Tausz (2007) noted “The timberline ecotone stretches from the forest line or upper limit of a continuous forest canopy to the tree limit which is the extreme upper limit of the occurrence of tree species.” (2) Holtmeier and Broll (2005) noted “The term treeline is applied to the transition zone extending from closed subalpine or northern forests to the uppermost or northernmost usually scattered and stunted individuals of the forest-forming tree species – regardless of their height. The upper or northern limit of the treeline ecotone is called the tree-limit.”

Besides, Finsinger and Tinner (2007) noted “The treeline ecotone spans the timberline and the tree species limit or krummholz limit.” In fact, more examples revealed that the ecotone terminology and its scopes are as individual as the persons (cf. Autio and Colpaert, 2005; Camarero et al., 2006; Holtmeier, 2009; Liu et al., 2002), also as the confused boundaries mentioned previously.

The concept of timberline or treeline ecotone is close to the forest–tundra ecotone (254 items in ISI; 247 items in GS by topic; 3,559 items in GS by all) or alpine timber-line/tree-line ecotone. Zeng et al. (2007) described the alpine forest–tundra ecotone as this transition zone from contiguous forest cover to open alpine tundra, being the elevational limit to the growth of tree forms and tree species and encompassing the range from upright trees to small patches of prostrate krummholz. Hence, the treeline or timberline ecotone is the transitional belt from timberline to krummholzline as proposed by Holtmeier (1981), Körner and Paulsen (2004), and Holtmeier and Broll (2007). In contrast, the forest–tundra ecotone may

be more suitable and more intuitive than the treeline ecotone or timberline ecotone for describing an area where the vegetation transition from the forested zone to the treeless zone is much more gradual (Löve, 1970). The usage of forest–tundra ecotone should be restricted to the subarctic region, because there is no significant differentiation between timberline, treeline, krummholzline, and forest–tundra ecotone at the continental scale or within the subtropics (Li and Chou, 1984; Schickhoff, 2005). Thus, we do not recommend the term forest–tundra ecotone to represent the sudden shift of vegetation in tropical or subtropical mountain ranges. If only a boundary must be used within/near the subtropical area, we prefer using the forestline, in contrast to treeline or timberline, to represent the forest edge when the vegetation shows a considerably abrupt transition.

Conclusion

Generally, low temperature limits tree growth and recruitment, particularly in high mountains (Fajardo and McIntire, 2012). The upper limit of woody plant forms the boundary from mountain closedforest to alpine treeless tundra. The width and form of boundary have been affected by internal driver (e.g. species) and external driver (e.g. environment). Because of the hedge between the diverse natural phenomena and different human languages in the world (Wilhelm, 2002), these boundary terms have various expressions and writing forms in different literatures, and are thus likely to result in ambiguities and difficulties during comparison.

In this paper, the concise terms and illustrations have been tried to serve for the human understanding intuitively. The concise scheme has been suggested, including timberline, forestline, treeline, krummholzline, and historic treeline, to replace some verbose and ambiguous terminologies. The 5 different boundary terms could facilitate the comprehension of spatial sequence of vegetation transformation in high mountain idealistically, however, all boundaries do not necessarily occur in all mountains of the world concurrently. We propose to use the term forest line, instead of timber line or tree line once recommended by others, to represent the boundary between forest and scrub or grassland when the vegetation transition is abrupt and conspicuous, particularly in the subtropical or tropical alpine. Besides, we propose to use the term forest–tundra ecotone to represent the transitional vegetation belt where the closedforest gradually transforms into the treeless tundra and spans a broad area, particularly around the subarctic. The use of simple terms to articulate ecological concepts can confuse ideological debates and undermine management efforts (Colautti and MacIsaac, 2004). To avoid the confusion from using these boundary terms, we suggest that authors studying boundary related issues should interpret their scope of terminologies and provide the basic description about environment and vegetation outlines in the complex high mountains.

Conflict of Interests

The authors have not declared any conflict of interests.

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