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Warm-Temperate Deciduous Forests around the Northern Hemisphere

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ISSN 2198-2562 ISSN 2198-2570 (electronic)
ISBN 978-3-319-01260-5 ISBN 978-3-319-01261-2 (eBook)
DOI 10.1007/978-3-319-01261-2
Springer Cham Heidelberg New York Dordrecht London

Library of Congress Control Number: 2014957871

Printed on acid-free paper

Springer is part of Springer Science+Business Media (www.springer.com)

Preface

The basic worldwide geographic framework for understanding relations between climate and plant or vegetation types involves the recognition of regular bioclimatic zones, such as tropical, temperate, and further subdivisions. In global bioclimatic zonation, one zone is the warm-temperate, which has generally warm (if not hot) summers and relatively mild winters, but with some frost, which distinguishes this zone from the tropical climates. Many warm-temperate climates are also generally humid, with year-round rainfall. As a result, the "zonal" (i.e., potential natural) vegetation of the warm-temperate zone is considered to be evergreen broad-leaved forest, such as the "laurel forests" of East Asia, southern Brazil, and the cloud belt of some parts of the Canary Islands. The trees typically have quite pliable, often glossy, thin-leathery evergreen leaves; build relatively deep root systems; and grow rapidly under the good climate conditions.

In some parts of the Northern Hemisphere, though, some more "southern" deciduous temperate (summergreen) forests, mostly oak forests, extend into the warm-temperate zone, where winters are just a bit too cold for the broad-leaved evergreen trees, though summers are still quite warm. That deciduous forests may occur regularly in the warm-temperate zone, under such conditions, was first recognized by the Japanese ecologist Tatsuō Kira, who called these forests "warm-temperate deciduous." This book represents the first attempt to recognize and describe "warm-temperate deciduous forests" as a consistent forest type representing a consistent response to similar climatic situations around the entire Northern Hemisphere. Most of the chapters included herein are from papers presented in 2011, in a special session on warm-temperate deciduous forests (also a first), held at the annual meeting of the International Association for Vegetation Science in Lyon.

Forest composition, structure, and environmental relations are treated in this book in various ways, some emphasizing bioclimatic relationships, some following traditional phyto-sociological analysis, plus some other methodologies. Some chapters on more specialized aspects are also included, in particular on various aspects of two prototype warm-temperate deciduous tree species, namely, downy oak (*Quercus pubescens*) from southern Europe and Chinese cork oak (*Quercus variabilis*) from East Asia. The book begins with a general overview chapter on the concept of warm-temperate deciduousness, and there is an attempt at the end to quantify the climatic limits of potential temperate forest regions and to map them accordingly, around the entire Northern Hemisphere.

As in any large area with diverse language and cultural regions, there are problems of terminology. The terms used herein for bioclimatic zonation represent what appears to be the global consensus on concepts, types, and names. The official Chinese national classification system is quite different, however, and some terms are in direct conflict. For example, in the Chinese system, *all* temperate deciduous forests have been called "warm-temperate" (despite winter temperatures to -30°C or lower), and all evergreen broad-leaved forests are usually assigned to the "subtropical" zone (if not tropical). For this book, only the more globally consistent terminology is used. This is explained in the "Overview" chapter, along with an attempt to explain the Chinese discrepancy.

Another difference involves people's names. In East Asia the family name comes first, followed by given names. For Japanese, there is no problem, because Japanese scientists follow the Western order quite consistently when using Western languages. Chinese and Korean names, on the other hand, are shown much less consistently, and it has become fashionable among eager young Chinese researchers to use the Western name order consistently, even when not dictated by their publishers. This can be quite confusing for people not familiar with Chinese and Korean names. Family names in both Chinese and Korean are normally of one syllable, followed usually (but not always) by two given names. The problem comes when there is only one given name (one syllable), but even this can be overcome simply by observing the pattern used for other names in the particular publication. In this book, Chinese and Korean names are given in their natural order (family name first), with the two given names hyphenated; Japanese names are given in Western order. The only exception is in some registered names of phytosociological syntaxa, which may be idiosyncratic.

Literature references are given in the direct, common-sense format used formerly by the Ecological Society of America. In this format, the first author (of multiples) has the family name first and subsequent authors follow with given and family names in their normal order – without inversions and without all those unnecessary, obfuscating commas that make the gothic, but now "accepted" format so difficult to read. Note that, in the format used herein, there is no comma in any Chinese or Korean name because there can be no inversions of family and given names.

Diacritical marks are unavoidable in order to retain some correct meanings and pronunciations, especially in Japanese. For long vowels, a macron is used on o (ō) and u (ū), while the other long vowels are indicated (as in written Japanese) by doubling the vowel, i.e., aa or ii, or by the convention "ei" for long e. Although it has recently become fashionable in Japan to omit macrons in Romanization, the difference between long and short vowels is not trivial. It represents different spellings, difference in syllable stress, and often quite different meanings. For example, short *o* means small (小) but long *ō* means large (大). Other things being equal, a syllable with a long vowel is much more likely to be stressed than one with only a short vowel – as also in English and most languages. In Chinese, each syllable carries one of four possible tones. Tone marks, though, are usually not shown herein, since these do not represent differences in spelling, either in *pinyin* (the Chinese phonetic Romanization system) or in Western renditions.

Finally, understanding some place names, especially in China, will be much easier if the reader is willing to learn just three East Asian words. A mountain (or mountains) is *shan* in Chinese and *san* in both Japanese and Korean; *ling* (Chinese) is a range of mountains. Thus, [the] Changbai-Shan is the mountains along the border between China and North Korea, Fuji-san is Mt. Fuji, and the Da Xing An Ling (Chinese) is the Greater Hinggan mountain range that separates Inner Mongolia (to the west) from Chinese Manchuria (to the east).

Sadly we must also note that Tatsuō Kira passed away in 2011, at age 91. He once told me (Box) that he kept his imagination young by dividing his scientific career into roughly 10-year segments, in each one of which he studied something entirely different from before. Perhaps this is a good model for many of us – his life was a model for all of us. It seems fitting, therefore, that we dedicate this book to his memory.

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Contents

Introduction: Why Warm-Temperate Deciduous Forests?

Elgene O. Box and Kazue Fujiwara

Warm-temperate deciduous forests would seem to be an enigma. In the various global (and globally aware) bioclimatic zonation systems, warm-temperate climates are generally construed as humid temperate climates with warm summers, mild winters (no lasting snow cover), and evergreen broad-leaved forest as the zonal (i.e. climatic potential) vegetation type. This is the general conceptualization both in global treatments of vegetation and climate, as by Rübel (1930), Schmithüsen (1968), and Walter (1968, 1970, 1985); and in regional systems, such as by Kira and others for East Asia (cf Kira 1945, 1949, 1977, 1991; Suzuki 1953; Miyawaki 1967). Such zonal evergreen broad-leaved forests occur in East Asia (often called "laurel forests") as well as in southern Brazil, northern New Zealand, parts of eastern Australia, in montane belts of tropical Asia (and even the Canary Islands), and, where topography permits, in small areas of the warm-temperate southeastern USA. Thermally, some mediterranean climates are also warm-temperate and may carry evergreen broad-leaved forests, albeit with sclerophyll rather than laurophyll foliage.

Even so, Tatsuō Kira (1949) recognized that deciduous forests may also occur as stable forests in some warm-temperate areas, if winters are too cold for evergreens. For these forests, especially some in interior Honshū (the largest island of Japan), he coined the term 'warm-temperate deciduous forest'. These deciduous forests occur not only as successional stages but may remain as permanent vegetation, even in some areas where winters are milder. In this sense, warm-temperate deciduous forests can be conceived as:

- "southern" temperate deciduous forests;
- occurring where summers are warm but winters are too cold for evergreens;
- occurring not only in Japan but also mainland East Asia, southeastern USA, and perhaps elsewhere; and
- including perhaps the "thermophilous" and "submediterranean" deciduous forests of southern Europe.

Why do such deciduous forests persist in warm-temperate areas? Are they anomalies, or are they a natural alternative in a consistent global zonation?

Warm-temperate deciduous forests (and more open woodlands) are a Northern Hemisphere phenomenon, resulting, like the boreal forest, from the continentality of the large Northern land masses (cf Troll 1948; Box 2002). Kira recognized the warm-temperate deciduous forests of Japan by observing that some deciduous *Quercus* species in Japan do not occur in either of the adjacent climatic zones, the cool-temperate to the north or the subtropical zone to the south. Indeed, throughout the Northern Hemisphere, warm-temperate deciduous forests are overwhelmingly oak forests. In East Asia these forests are composed especially of deciduous *Quercus serrata*, *Q. variabilis*, *Q. aliena* and *Q. dentata*. These species form forests in the drier climates of interior Honshū, such as around Nagano, where summers are warm but winters are colder. Minimum winter temperature in these areas can go below −15°C (not below −20°C), mean January temperature is around 0°C, and values of Kira's Coldness Index are below −10°C. Average annual precipitation may be 900–1100 mm, which is low for Japan.

Similar deciduous forests also occur in the relatively warm climates of north-central to eastern China and the more southern lowlands of Korea; analogous deciduous forests beyond Asia appear to include the *Quercus pubescens* forests of the Mediterranean area and the oak-hickory (*Quercus-Carya*) forests of interior southeastern North America. In East Asia, the main warm-temperate

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E.O. Box and K. Fujiwara (eds.), *Warm-Temperate Deciduous Forests around the Northern Hemisphere*, Geobotany Studies, DOI 10.1007/978-3-319-01261-2_1,

deciduous species generally occur on relatively dry sites and are the same species that form the canopy of successional deciduous forests that are eventually replaced by zonal evergreen broad-leaved forests. In eastern North America, some deciduous tree species have distinctly northern or southern ranges, making the concept of warm-temperate deciduousness relatively clear. Areas of potential warm-temperate deciduous forest around the Northern Hemisphere can be suggested from climatic considerations, as shown in the last chapter of this book (Box). In the Southern Hemisphere, temperate deciduous forests occur naturally only in the southern Andes, but the climate is much too cool to consider them warm-temperate.

Most chapters in this book come from papers presented at the 2011 annual IAVS meeting, in Lyon, in a special session on warm-temperate deciduous forests, which was the idea of the second author. The purpose of that session was to try to clarify some of the climatic and related questions about warm-temperate deciduous forests as a true forest type. Local and regional specialists were invited to present descriptions of the warm-temperate deciduous forests in their areas, with whatever further analysis seemed appropriate. This session was the first to focus on warm-temperate deciduous forests as a recognized type within a global framework. Some initial goals were to:

– Document the composition and structure of these forests, as well as their landscape dynamics
– Examine and compare their environmental situations, including but not limited to their Climatic similarities (and differences)
– Understand why these deciduous forests are not replaced by evergreen broad-leaved forests.

Particular questions include the following:

– What are warm-temperate climates?
– What is a warm-temperate deciduous forest (composition, ecology, etc.)?
– What are the relative advantages of evergreen and deciduous trees in such climates?
– Why do deciduous forests persist and evergreens not dominate if the climate is warm enough for them?
– Are there significant differences among ‘thermophilous’, ‘submediteranean’ and ‘warm-temperate’ deciduous forests, in Europe or elsewhere?

The chapters in this book are mostly from papers presented at the Lyon meeting, but a few papers were added later, since they expanded on the topic.

The first chapter (Box and Fujiwara), after this brief introduction, provides a world overview of warm-temperate deciduous forest areas, including attempts to define the term. This is followed by regional treatments, starting with East Asia, proceeding through Europe to eastern North America, and ending with the drier west-side situations of California and parts of the Middle East. In East Asia, the national climatic classification system of China also uses the term ‘warm-temperate deciduous forest’ but in a different sense, since their classification is based mainly on the growing season and not on the climate of the whole year. As a result, Chinese usage is not equivalent to our global concept of warm-temperate deciduous forest, although warmer parts of the Chinese deciduous forest region probably are warm-temperate. This is explained in the overview chapter and elsewhere (e.g. Box 1995a; Box and Fujiwara 2012).

The next chapter, by Fujiwara and Harada, presents a detailed phytosociological comparison of East Asian temperate deciduous forests, including those from many areas in China, based on extensive fieldwork and analysis of relevé data. These temperate forests are mainly dominated by beech (*Fagus*) or oaks (*Quercus*), but the warm-temperate deciduous forests are overwhelmingly oak forests. This chapter represents one of the few truly comprehensive treatments of any forest type across East Asia as a whole (cf Fujiwara et al. 2008), comparing forest composition, environmental limitations, and identifying many new phytosociological syntaxa (and reinterpreting some existing syntaxa). This chapter also includes a map of current actual warm-temperate deciduous forest locations and another showing where these forests are permanent or successional to evergreen forests. There is also an extensive list of references to East Asian literature, most of which was conceived within national borders. This chapter represents a major phytosociological synthesis of information on deciduous *Quercus* forests of East Asia.

In East Asia, *Quercus variabilis* (Chinese cork oak) is a prototypic warm-temperate deciduous tree species, occurring from north-central China to Korea and Japan. It occurs both as a secondary tree and as the dominant or co-dominant of persisting warm-temperate deciduous forests. Despite some confusing terminology (cf Preface), *Quercus variabilis* does seem to be a truly warm-temperate deciduous tree. The situations and phytosociological units in which it occurs are described in detail by Tang et al. (herein), who offer an ordination and define several new alliances as well as a new order and class. At the end of this chapter is the suggestion that the southern boundary of the Chinese zone called warm-temperate be moved further south, which would bring it more in line with global zonations. This should be accompanied, though, by a southward shift of the northern boundary of this zone (and perhaps of the “temperate” zone itself).

The largest part of the book treats southern Europe, where *Quercus pubescens*(downy oak) can be considered a prototypic warm-temperate deciduous tree. It occurs from northern Iberia to the Black Sea region, with some outliers beyond. Within southern Europe, we begin with a description by Costa et al. (herein) of vegetation mosaics in the transition, in Portugal, between the Euro-Siberian nemoral forests to the north and the Mediterranean, or at least submediterranean, vegetation to the south. Deciduous forests over much of Europe involve *Q. robur*, the most widely occurring species. In central Portugal, forests of *Q. robur* ssp. *broteroana* (in a Viburno tini – Querceto roboris) are seen as warm-temperate deciduous, and forests of an Arisaro-Quercetum broteroi as intermediate between warm-temperate deciduous and Mediterranean, i.e. submediterranean.

The Iberian peninsula represents a fairly broad transition from nemoral to Mediterranean conditions, and northern Spain has some fairly extensive areas of deciduous oak forest. Various features of Iberian oaks are described and interpreted by Garcia-Mijangos et al. (herein) as adaptations to the nemoral, submediterranean or Mediterranean climatic conditions. Marcescence, in particular, seems not to be a lingering vestige of the evergreenness that it suggests, but rather a characteristic of submediterranean conditions. Other adaptations are also considered, such as semi-evergreenness, as well as advantages of evergreenness and deciduousness in transitional situations. All of these phenological adaptations occur also in other oaks in other climates: what do they have in common?

Downy oak (*Quercus pubescens* s. l.) is a prototypic warm-temperate deciduous tree species in Europe and is treated in three chapters. Its distribution and ecology in Italy, as well as its polymorphisms and difficult taxonomic history, are considered by Guarino et al. (herein), who note that the widest range of forms and ecological conditions is found in Sicily, where some commonly competing trees are missing. Differences in Sicily do not seem to be related to clear ecological or geographical discontinuities. *Q. pubescens* is also an important species in the long-managed landscapes of interior central Italy, where it occurs mainly in coppices. Its potential in the Marche region, at landscape scale, is considered by Cianfaglione (herein). Finally, taxonomic and other, mainly historical problems of *Q. pubescens* and related taxa are treated by Wellstein and Spada, based on a comprehensive literature review including the classic monographs on European oaks. *Q. pubescens* has long been considered a "species complex", but the actual species status of some other well known, named oaks in southern Europe is also questioned.

Two other oak species are also treated in detail. One is *Quercus petraea*, which occurs widely in deciduous forests of Europe and looked quite like a "southern" species when its climatic range was projected to North America (Box and Manthey 2006). Its situation as a potential warm-temperate deciduous species is considered by Pedrotti (herein) in the transitional forests of northern Italy. *Quercus suber*, on the other hand, is evergreen but may lose some foliage in winter and is interestingly related to some of the deciduous oaks of southern Europe. Its long history and possible occurrence much further east than at present are considered in a deeply researched chapter by Schirone et al. (with Spada, Simeone, Vessella, herein) that suggests a model for historical study of other Mediterranean species as well. The same co-authors (mostly) also provide an interesting perspective on forest refugia in Europe during the last glacial period (Schirone, Spada, Piovesan and Simeone, herein).

Eastern North America may have the world's largest area of warm-temperate deciduous forests, in roughly the southern half of its eastern deciduous forest area. The deciduous forests of the interior southeastern USA occur under conditions of warm summers and milder winters than at comparable latitude and geographic position in East Asia, where forests are usually broad-leaved evergreen. The forests of the interior southeastern USA are deciduous, however, because of infrequent but extreme low-temperature events (cf Box 1995a). Various types of American warm-temperate deciduous forest are described (Box, herein), with relevé data and with climatic data provided in the Appendix to this book.

Regional coverage concludes with two chapters covering drier, west-side situations, in which the vegetation is generally not closed forest. Both chapters are from Blumler, who has studied the advantages of deciduousness in mediterranean climates for many years (e.g. Blumler 1991). The first chapter (Blumler, herein) concerns California, where deciduous oaks occur and dominate, mainly in open woodlands, under submediterranean and sometimes truly Mediterranean-like climatic conditions. The second region involves parts of the interior Middle East, which is treated by Blumler and Plummer (herein) in comparison with California. Large areas from the Levant to Iran have (interior) Mediterranean climatic conditions but are dominated by deciduous trees, usually in open woodlands or scrub, rather than the evergreen sclerophyll scrub of other areas with mediterranean climate.

Finally, in the last chapter (Box, herein), an attempt is made to delimit warm-temperate deciduous and other temperate climatic regions quantitatively and to map their geographic areas based on postulated climatic envelopes (cf Box 1981, 1995b, c). It is seen in the "overview" chapter (Box and Fujiwara, herein) that the thermophilous and submediterranean deciduous forests of southern Europe occur under distinctly cooler summer conditions than in East Asia and eastern North America. This does not disqualify them as warm-temperate deciduous forests but suggests that the concept must be seen as relative to conditions over the whole of the particular large regions concerned.

Taken together, these chapters represent a first attempt to recognize warm-temperate deciduous forests as a consistent, alternative forest type in the Northern warm-temperate zone and to explore what they have in common. With global warming, warm-temperate deciduous forest areas may well become battlegrounds between deciduous and evergreen elements, as suggested by the 'laurophyllization' phenomenon described already in southern Switzerland (Klötzli and Walther 1999). So knowledge of these areas is important, and we hope this comparison will be useful.

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Warm-Temperate Deciduous Forests: Concept and Global Overview

Elgene O. Box and Kazue Fujiwara

Abstract

The zonal vegetation of [humid] warm-temperate regions is normally considered to be evergreen broad-leaved forest, such as the "laurel forests" of East Asia, southern Brazil, and much of New Zealand. Observing the vegetation of Japan and other parts of East Asia, however, Kira noted in 1949 that some deciduous *Quercus* species do not occur in either the cool-temperate (deciduous) or the subtropical (evergreen) zone and eventually proposed the concept of warm-temperate deciduous forest, composed especially of *Quercus* species. These species occur in the drier climates of interior Honshū, especially around Nagano, where summers are warm enough but winters are too cold for evergreen broad-leaved forest. This concept also fits parts of middle-eastern China and lowland Korea, where most of the same *Quercus* species also occur. Analogous warm-temperate deciduous forests beyond Asia appear to include, *inter alia*, the *Quercus*-*Carya* forests of interior southeastern North America and the *Quercus pubescens* forests of southern Europe. In East Asia, some main deciduous species are *Quercus variabilis*, *Q*. *serrata*, *Q*. *aliena* and *Q*. *dentata*, all occurring on mesic to dry sites. These species also form the canopy of secondary deciduous forests that are eventually replaced by the zonal warm-temperate evergreen broad-leaved (laurel) forests. In eastern North America, some *Quercus* and other deciduous taxa (including *Fagus*) have wide north-south ranges, but deciduous *Q*. *falcata*, *Q*. *nigra*, and others have distinctly southern ranges. This southern area is in the warm-temperate zone and has mean winter temperatures significantly higher than in East Asia (albeit with unusual lower extremes). Warm-temperate deciduous forest analogs around the Northern Hemisphere can be identified from climatic considerations but also from phytosociological analysis (and ordinations) based on relevé data, suggesting that this is a consistent subzonal forest type.

Keywords

Absolute minimum temperature • Climatic zonation • Cool-temperate climate • Deciduousness • Evergreenness • Kira index • Summer warmth threshold • Submediterranean climate • Thermophilous deciduous forest • Typical temperate climate • Warm-temperate climate • Zonal vegetation

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1 Introduction

The idea of warm-temperate deciduous forest derives from Tatsuō Kira, the imaginative Japanese ecologist who made the first modern climatic zonation system for much of East Asia (Kira 1945) and used it to explain potential forest

E.O. Box and K. Fujiwara (eds.), *Warm-Temperate Deciduous Forests around the Northern Hemisphere*, Geobotany Studies, DOI 10.1007/978-3-319-01261-2_2,

Table 1 Forest zones of humid East Asia as defined by Kira's warmth index and coldness index

	Warmth Index	Coldness Index	Mean annual temperature
Arctic	0–15°		
Subarctic (evergreen conifer)	15–45°		
Cool-temperate			
Deciduous broadleaf	45–85°		
Mixed broadleaf + conifer	>45°		
Warm-temperate			
Evergreen broadleaf	85–180°	>−10°	>20°
Deciduous broadleaf	>85°	<−10°	
Subtropical	180–240°		20–25°
Tropical	>240°		>25°

The Warmth Index is defined as the annual sum of monthly mean temperatures above a 5°C threshold; the Coldness Index is the annual sum of monthly mean temperatures below 5°C. Warm-temperate evergreen and deciduous are differentiated by the degree of winter cold. No climatic distinction is specified between cool-temperate deciduous and mixed forest zones. All values are in degrees Celsius or equivalent annual temperature sums.
Source: Kira (cf 1977, 1991)

zones, initially in Japan (Kira 1949, 1977). The system was quantified by means of Warmth and Coldness Indices (WI, CI), which represent temperature sums above and below a growth threshold of 5°C (see Table 1). With WI and CI values it was possible to distinguish tropical, subtropical, warm-temperate (evergreen), cool-temperate (deciduous), and subarctic (boreal) zones and their potential (zonal) vegetation, including some belts in mountains. The system was also applied to Korea (Yim 1977; Yim and Kira 1975–1976) and eventually to much of mainland East Asia (Kira 1991), in order to explain vegetation patterns for all of East Asia first described by Suzuki (1952, 1953).

Even so, Kira (1949) also recognized that some deciduous *Quercus* species do not occur in the cool-temperate deciduous zone but rather in the warm-temperate zone, in which the zonal vegetation was supposed to be evergreen broad-leaved "laurel forest" (the *Lorbeerwald* of Rübel 1930; Schmithüsen 1968, and other European writers). For these warmer-climate deciduous *Quercus* species Kira coined the term 'warm-temperate deciduous forest' to refer to stable deciduous forests occurring under conditions warm enough for warm-temperate broad-leaved evergreens but with winter temperatures too low for evergreens. These forests are composed especially of *Quercus* species and occur in the drier, somewhat more continental climates of interior Honshū, especially around Nagano and Ueda, where summers are warm enough (WI > 85°) but winters are too cold (CI < −10°) for evergreen broad-leaved forest. Minimum winter temperatures in these areas can go below −15°C (but not below −20°C); mean annual temperature is around 11°C, and average annual precipitation may be 900–1100 mm, which is low for Japan.

This description also fits some regions in middle China and southern Korea, and seems to describe some areas beyond Asia, such as large parts of the interior southeastern USA and parts of southern Europe. Included in particular might be the deciduous oak-hickory (*Quercus-Carya*) forests and "Southern mixed hardwoods" (Quarterman and Keever 1962) of the southeastern coastal plain of the USA (cf Braun 1950; Greller 1989); and the 'thermophilous' (e.g. Čarni et al. 2009) and 'submediterranean' (e.g. Meusel and Jäger 1989) deciduous forests across southern Europe from the Iberian peninsula to the Hyrcanian region. Note that this is not the Chinese sense of 'warm-temperate', a term applied to all temperate deciduous forests (see, *inter alia*, Hou 1983; Zhao 1986).

The collection of papers in this book, designed originally for *Braun-Blanquetia*, is from the 2011 meeting of the International Association for Vegetation Science in Lyon, as presented in a special session dedicated to understanding "warm-temperate deciduous forests" and why they occur. This current paper attempts to provide a background for this discussion by presenting relevant climatic zonation and posing questions about the ecology of such forests. For example, what are warm-temperate deciduous forests, why do they occur, why do evergreens not dominate in these forests, and what are the relative advantages of evergreenness and deciduousness in warm-temperate climates? Finally, an initial attempt is made to identify the apparent boundaries of warm-temperate deciduous forests, both climatically and in terms of the vegetation.

2 Climatic Zonation

Climatic zonation began with the basic division of the world into torrid (tropical), temperate and frigid (polar) regions by Aristotle, around 350 BC. The Earth is still usually divided in this way, into 'tropical' regions with no frost

Table 2 Basic concepts of humid temperate and adjacent climates

Main world divisions, based on frost severity and occurrence		
Tropical	No frost ever	Always warm, little temperature seasonality
Temperate	Seasonal frost	Warm summers, colder winters, frost slight to severe
Polar	Frost all year	Even summer frost; extreme day-length variation
Temperate climates, based on summer and winter temperatures		
	Warm summer	*Cool summer*
Mild winter	Warm-temperate	cool-temperate
Cold winter	Typical temperate	cool-temperate
Resulting zonation, with zonal vegetation types		*Forest type*
Boreal	Continental, with severely cold winters and pleasant summers	Coniferous
Temperate	Four distinct seasons, summers cool to quite warm, significant winter frost; generally 4 months or more >10°C	
Cool-temperate	Cool summers, winters mild to cold	Deciduous/mixed
Typical temperate	Largest region, generally subcontinental, with warm season usually 5–6 months	Deciduous
Warm-temperate	Warmer, still longer summers, usually 6–8 months; winters mild enough for evergreens (mean temperatures >0°C)	Evergreen mixed/ broad-leaved
Subtropical	Almost tropical, i.e. almost frost-free and warm [almost] all year	Evergreen broad-leaved

The three-part division in part (a) was first suggested by Aristotle and has provided the basic global framework for climate classification ever since. Humid temperate climates (part b) can be divided based on summer and winter temperature levels. Typical temperate climates are subcontinental, with warm summers and cold winters. Warm-temperate requires a milder winter, as may occur at lower latitudes or near the coast, as well as a fairly warm summer. Cool-temperate has cooler summers, which may derive from higher latitudes or oceanic effects (winters may be mild, e.g. oceanic, to quite cold). To the north (part c), boreal climates generally have more severe winters and summers not warm or long enough for temperate-zone broad-leaved trees. To the south, subtropical climates are almost tropical but still may have light frost occasionally, perhaps only a few times in a century. Some other temperature limits are suggested in the main text.

(at least in lowlands), mid-latitude or 'temperate' regions with frost increasing poleward, and 'polar' regions with frost possible at almost any time of year (Table 2). The transitions between these regions are called 'subtropical' and 'subpolar'.

Modern climate classifications are normally based either on quantitative indices for separating climate types (e.g. Köppen 1931) or on the mechanisms of atmospheric circulation that generate particular climate types (e.g. Walter 1977; cf Flohn 1950). In higher to middle latitudes of the Northern Hemisphere, both the quantitative and genetic (i.e. mechanistic) approaches recognize a polar zone with very cool, short summers (not frost-free); a boreal zone with long, severely cold winters but short, pleasant summers too warm to be truly subpolar; and a temperate zone with warm summers but still significant frost in winter (e.g. Troll and Paffen 1964; Walter 1968, 1977, 1985; Hämet-Ahti et al. 1974; Box and Fujiwara 2005, 2013).

Except in drier continental interiors, the most typical temperate climate is expressed as a humid subcontinental climate with warm summers, cold winters with significant frost, and four characteristic seasons of roughly equal length. One can also recognize subtypes based on the relative warmth or coldness of the summers and winters:

- a cool-temperate climate, with cooler summers (often oceanic, with mild or cold winters); and
- a warm-temperate climate, with milder winters, warmer summers, and a longer growing season.

Forests in the typical-temperate and cool-temperate regions are usually deciduous, while forests in warm-temperate regions are at least potentially evergreen (broad-leaved), unless winters are too cold. Mild winters generally have mean temperatures above freezing (perhaps well above) and no persisting snow cover. Winters too cold for evergreen forest generally have mean temperatures below about −1°C (Fujiwara 1982) or absolute minima below about −15°C (Woodward 1987; Box 1995; cf Sakai 1971).

On the other hand, Japanese writers traditionally recognized only two temperate subdivisions, warm and cool, though a "middle temperate zone" was also suggested (e.g. Yamanaka 1956). The Chinese zonation also recognizes two subdivisions, cold-temperate and warm-temperate, but uses the terms quite differently. The global zonation of Walter (1977) also recognized only two types, warm-temperate and nemoral, with the latter corresponding more to the cooler, higher-latitude climates of Europe.

On continental east sides, mid-latitude climates tend to be more continental and the humid temperate zone broader (cf Box 1995; Box and Fujiwara 2013). Both vegetation and climatic patterns over the large north-south extent of deciduous forests, especially in eastern North America and most of East Asia, argue strongly for the division into three sub-zones:

– a cool-temperate zone with cooler summers (due to higher latitude or oceanic influence), usually with significant admixtures of non-boreal conifers such as *Pinus koraiensis* or *P. strobus*;
– a main, generally subcontinental 'typical temperate' zone, with four seasons of roughly equal expression and more completely deciduous forests (without conifers at maturity); and
– a warm-temperate zone with milder winters, quite warm-sultry summers, and normally evergreen broad-leaved forests as the zonal vegetation, unless winters are too cold.

Logic suggests that the typical temperate should represent the widest portion, with cool and warm-temperate as smaller sub-zones possessing some transitional character.

This three-part zonation is used here because it conforms better to all parts of the Northern Hemisphere. By this scheme, most of Hokkaidō is cool-temperate and the northern half of Honshū is typical temperate (i.e. the range of lowland or foothill *Fagus* forests); Manchuria (including the Russian Far East) and subhumid southeastern (Chinese) Mongolia are mostly cool-temperate and much of North China is typical temperate; Korea is mainly cool-temperate in the north and typical temperate in the middle and south. To the south, much of eastern China, southern Japan, and the southern coast of Korea are warm-temperate, with evergreen broad-leaved forests unless winters are too cold. Eastern North America fits this three-part scheme well, with a large typical-temperate region in the middle (cf Greller 1989); it would not fit the two-part scheme because cool-temperate (cool summers) would apply only to New England and adjacent, but mild winters (warm-temperate) do not appear (southward) until one reaches the southeastern coastal plain, leaving a large (typical temperate) gap in between. Europe is mostly cool-temperate north of the Alps, due to the higher latitude and oceanic influence, but typical temperate to warm-temperate in the submediterranean south. In mountains of the temperate zone, the montane belt corresponds generally to cool-temperate (with mixed forests) in the typical temperate zone and to typical temperate (with more completely deciduous forests) in the warm-temperate zone. Subalpine belts correspond generally to boreal (with conifer forests), and alpine belts (above treeline) correspond to the polar zone, with treeless vegetation.

3 Warm-Temperate Regions

Warm-temperate climates are thus normally understood to be mostly humid temperate climates with:

– warmer summers and a longer growing season; and
– milder winters, with mean temperatures above freezing and no persistent snow cover.

The warm-temperate climate was included in Walter's system of world climate types, but as a type V that could occur on both the west and east sides of continents (cf Walter and Lieth 1960–1967). Various authors have recognized this one (and only) logical flaw in Walter's system and have separated type V into a 'marine west-coast' climate resulting from pervasive oceanic influence at higher latitudes on the windward west sides of land masses; and a warmer, truly 'warm-temperate' type found at lower latitudes on east sides of land masses. Our concept herein is the latter, involving zonal laurophyll forests, as in East Asia, southern Brazil, northern New Zealand, and even some montane belts in the Canary Islands and small topogenic areas of the southeastern USA. The relative positions of these and all the Walter climate types are shown on an "Ideal Continent" in Fig. 1, and a full global zonation scheme based on Walter has been given by Box (2002; cf Box and Fujiwara 2005).

Within warm-temperate regions of the Northern Hemisphere (see Table 3), one can also recognize the following subdivisions and transitions (with Walter-based notations):

– a main warm-temperate region (Ve), with evergreen broad-leaved forests;
– a subtropical transition (Ve-II), with milder but also drier winters (generally still evergreen);
– a poleward transition (Ve-VI and VI-Ve), with more significant frost (becoming deciduous); and
– a transition toward drier continental interiors (Ve-VII), with somewhat colder winters and conditions generally too dry for closed forest (e.g. the evergreen oak woods of central Texas).

On continental west sides, mediterranean climates represent a thermal counterpart to warm-temperate (and subtropical), but with dry summers. Up to the point where summers become too dry, the transition from nemoral to mediterranean (VI-IV) produces 'submediterranean' conditions that can involve deciduous forest and can be quite similar to our warm-temperate deciduous concept. Submediterranean climates were characterized by Sánchez de Dios et al. (2009) as involving lower winter mean temperatures than mediterranean (-1° to +3°C) and temperatures in general, as well as annual and summer precipitation amounts, that are intermediate between nemoral and mediterranean.

In Japan, Korea, and the Russian Far East, zonation schemes have largely followed global concepts and terminology (cf Box and Fujiwara 2005, 2013; Box and Choi 2003).

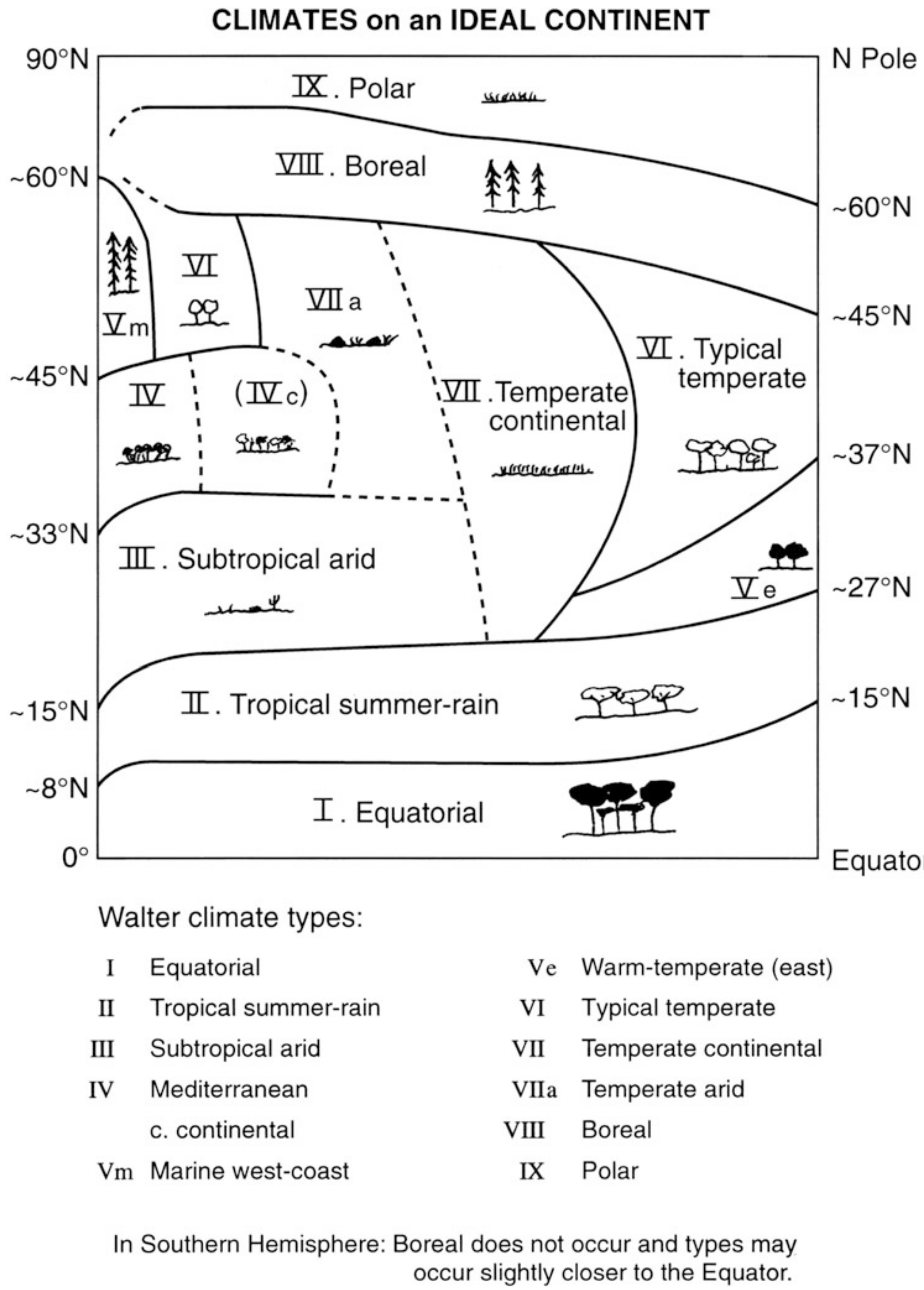

Fig. 1 Climatic regions on an ideal continent. The climates are the genetic climate types of Walter (1977; cf 1968, 1973, 1985), modified by splitting the original Walter V climate into marine west-coast (Vm) and warm-temperate east-coast (Ve) types, due to the quite different atmospheric mechanisms which produce them

The Chinese national zonation system is quite different, however, focusing on the growing season and not the climate of the whole year (see English-language summaries by Tietze and Domrös 1987 and by Zhao 1986). The Chinese system was developed in the 1950s (Physical Regionalization Committee 1958–1959), influenced by the more northern perspective of Russian thinking of that time. The Chinese system (e.g. China Natural Geography Editorial Commission 1984) includes zones called liáng wên (温, = cool-warm), translated as cool-temperate, and nuăn wên (暖温, = warm-warm), translated as warm-temperate. The problem arises when 'cool-temperate' is applied to the zone of boreal conifer forests and 'warm-temperate' for the zone of temperate deciduous forests, including places like northern (Chinese) Manchuria, where January mean temperatures are around −20°C and extremes drop to around −40°C (see Appendix). This is not the mild winter of a warm-temperate climate and may not even seem very "temperate" at all. The climate is so ultra-continental, in fact, that the nemoral forest zone (with 4–5 warm months) is truncated in some places by the sudden appearance of permafrost and boreal forests, with no transition (Box et al. 2001).

Table 3 Types of warm-temperate climate and corresponding woody vegetation

Warm-temperate type	Walter climate	Vegetation	Examples
Humid warm-temperate (classic concept)	Ve	Evergreen broad-leaved "laurel" forests of mainly temperate tree taxa	East Asia, S Brazil, Florida (except south)
Mediterranean (thermally warm-temperate)	IV	Evergreen woods/scrub	Mediterranean region, most of California (cf submediterranean Europe, IV-VI)
Warm-temperate deciduous	VI-Ve	Deciduous forests composed of "southern" or "thermophilous" taxa	Interior Japan, interior northern-eastern China, interior southeastern USA, southern Europe
Warm-temperate mixed	Ve-VI	"Mixed" semi-evergreen forests (e.g. "southern mixed hardwoods")	Central-interior southern China, SE US coastal plain, parts of southern Europe (cf submediterranean)
Dry warm-temperate	Ve-VII	Woodlands of mainly evergreen broad-leaved trees (e.g. oaks)	Central Texas; much of Australia
Humid subtropical	Ve-II	Evergreen broad-leaved "laurel" forests of mainly (sub)tropical tree taxa	Southern China, mountains of SE Asia

The Roman numerals represent the climate types of Heinrich Walter, the most widely used genetic system of global climate types (see Walter 1977; Walter and Lieth 1960–1967; Walter and Box 1976). Warm-temperate climates (Ve) are the east-side portions of Walter's original type V, with the west-side portion called marine west-coast (Vm) (see Fig. 1; cf Box 2002; Box and Fujiwara 2013). Warm-temperate climates include the main warm-temperate zone (Ve) plus its transitions: to subtropical, with drier winters (Ve-II); to typical temperate, with still mild winters (Ve-VI) or cooler winters (VI-Ve, more completely deciduous); and to drier temperate continental (Ve-VII). Thermally, mediterranean climates are also generally warm-temperate, at least on their poleward side (subtropical toward the equator). Submediterranean climates (IV-VI) that are still humid enough for forest or woodlands may thus also represent a kind of warm-temperate climate.

Furthermore, the term 'subtropical' is applied to the entire southern half of eastern China, beginning where January mean temperatures are below 5°C.

A very useful summary of the Chinese system has been provided more recently by Fang et al. (2002), explaing how the system developed from a basis in mean temperatures through 'accumulative temperatures', potential evaporation, and heat sums such as Kira's indices. All of these, however, focus on the warm season, without reference to the low temperatures that actually limit many vegetation types and zones. General concepts and terminology should reflect conditions over the entire year, not just seasons of particular interest, such as agricultural growing seasons. Terminology and classifications should also respect the meanings of the words used: for example, regions called 'sub' should not be larger than their base regions. Some of these Chinese terms are inappropriate and out of step with global zonation systems.

Another problem involves the delimitation of the warm-temperate versus humid subtropical zones, since both normally have evergreen broad-laurophyll forests with very similar physiognomy. The difference is in the floras, as suggested in Table 4. Mature evergreen forests are composed mainly of (sub)tropical taxa in the subtropical zone but mainly of temperate taxa (e.g. *Castanopsis*, *Cyclobalanopsis*, *Persea*, *Magnolia*) in the warm-temperate zone. The transition from one flora to the other is gradual in China, making delimitation difficult. In Florida, on the other hand, the temperate flora is replaced almost completely by a subtropical flora within the north-south distance of about 100 km, beginning just south of a town appropriately named Frostproof (Crumpacker et al. 2001). In addition, after disturbance (and after some deciduous pioneers such as *Mallotus*), the secondary forest vegetation in the subtropical zone is mainly evergreen and also composed mainly of (sub)tropical taxa. The secondary forest vegetation in the

Table 4 Subtropical versus warm-temperate humid climates and vegetation

	Zonal forest (terminal stage)	Secondary forest (after pioneers)
Subtropical (Tabmin > −2°C)	Evergreen (tropical taxa)	Evergreen (tropical taxa)
Warm-temperate (Tabmin > −15°C)	Evergreen (temperate taxa)	Deciduous (temperate taxa)

Humid subtropical and warm-temperate climates both generally have evergreen broad-leaved forest as the zonal vegetation type. In addition to their limits for extreme low temperatures (Tabmin, absolute minimum temperature), these zones may also be differentiated by their secondary vegetation and their floras. In the subtropical zone, the secondary (woody) vegetation that arises after disturbance (after an initial stage of pine or other conifers) is mainly evergreen and composed of (sub)tropical taxa. In the warm-temperate zone, the secondary woody vegetation is largely deciduous and composed of temperate taxa, including many of the main trees of permanent warm-temperate forests (cf Miyawaki and Fujiwara 1983).

Table 5 Warm-temperate deciduous regions and some main taxa, especially oaks

Region	Main species	Locations	References
East Asia	*Quercus serrata*, *Q. variabilis*, *Q. aliena*, *Q. acutissima*; plus *Aphananthe aspera*, *Celtis sinensis*	Central Honshū (Japan)	Kira 1949; Karizumi 1956; Yamanaka 1956; Miyawaki et al. 1971; Miyawaki 1980–1989
		Eastern-central China	Wang 1961; Wu 1980; Chen 1995; Tang et al. 2008; You et al. 2008
		Interior Korean peninsula	Yim 1995; Kim 1990
Eastern N America	*Quercus falcata*, *Q. nigra*, *Q. phellos*, *Q. laevis*, *Q. texana* (red group); *Q. muehlenbergii* (white group); *Liquidambar*	Interior coastal plain of southeastern USA	Braun 1950; Quarterman and Keever 1962; Christensen 1988; Greller 1989; Box and Manthey 2006
Southern Europe (+ N Africa)	*Quercus pubescens*, *Q. cerris*, *Q. petraea*		Quézel and Médail 2003; Ozenda 1994
	west: *Q. broteroi*, *Q. canariensis* (semi-decid); *Q. pyrenaica*, *Q. faginea* (marcescent)	Northern Iberian peninsula	Morla and Pineda 1985; Moreno et al. 1990; Sánchez de Dios et al. 2009
	N Afr: *Q. afares* (+ *Q. can.*, *Q. pyr.*)	Interior northern-central Italy	Blasi et al. 1999; Pignatti 1998
		Maghreb mountains	Quézel and Médail 2003; Tessier et al. 1994
	east: *Q. frainetto*	Interior Balkan peninsula	Horvát et al. 1974; Bergmeier et al. 2004; Čarni et al. 2009; cf Horvát 1959
Euxino-Hyrcanian region	*Quercus iberica*, *Q. macranthera*, *Q. pontica*; *Q. castaneifolia*; + *Q. pubesc.*, *Q. petraea*, *Q. cerris*; plus *Pistacia*, *Amygdalus*, *Crataegus*, *Pyrus*, *Cerasus*, *Celtis* spp. *Zagros*: *Q. brantii*, *Q. infectoria*, *Q. libani*		Zohary 1973–1974; Browicz 1978–1988,
		Northern & eastern Turkey	Ugurlu and Gökhan Senol 2005; Kavgaci et al. 2010; Kargioglu et al. 2011; Ugurlu et al. (in press)
		Colchis, S slopes of Caucasus southern Azerbaijan	Nakhutsrishvili 2012; Klein and Lacoste 1989; Scharnweber et al. 2007
		Hyrcanian Iran	Akhani et al. 2010; Zohary 1963
		"Zagros gap"	Blumler (herein - a)
California-Oregon	*Quercus lobata*, *Q. douglasii*, *Q. kelloggii*, *Q. garryana*; *Q. engelmannii* (semi-evergr.)	Foothills around central valley and in southern Oregon	Barbour et al. 2007; Mensing 2005–2006; Blumler (herein - b)
Mexico	*Quercus xalapensis*, *Q. eduardii* (red group); *Q. insignis* (white group); *Liquidambar*, *Carpinus*	Mid-elevations of Sierra Madre Oriental	Kappelle 2006; Borchert et al. 2005; Rzedowski 1978; Miranda and Sharp 1950

The East Asian species dominate both permanent warm-temperate deciduous forests and secondary stages leading to zonal evergreen laurel forests. In the US, *Q. phellos* and *Q. nigra* are both "tardily deciduous" (the latter semi-evergreen toward the south). In the Middle East, *Q. macrolepis* and *Q. ithaburensis* are both at least semi-evergreen.

warm-temperate zone, on the other hand, is mainly deciduous and involves temperate taxa such as *Quercus serrata* and *Q. variabilis* in East Asia or *Q. nigra* in Florida, which are also major species of the (persisting) warm-temperate deciduous forests in these regions (cf Miyawaki et al. 1971).

4 Warm-Temperate Deciduous Regions and Taxa

Warm-temperate climates differ from "typical temperate" or nemoral climates by having milder winters, which permit evergreen broad-leaved forests to be seen as the zonal vegetation type, as in the case of the laurel forests of East Asia and southern Brazil. Warm-temperate deciduous forest areas with colder winters, however, do occur and can be expected in transitions from nemoral climates with deciduous forests (e.g. the Euro-Siberian region) to warmer, more southern regions with evergreen broad-leaved vegetation. The main potential regions of warm-temperate deciduous forest are shown in Table 5 and include East Asia, southeastern North America, and southern Europe; the Southern Hemisphere has no warm-temperate deciduous forests because summers are too cool. Also shown in Table 5 are the main deciduous (including semi-deciduous) tree taxa and literature descriptions of the local vegetation.

The most important single taxon is the deciduous oaks (*Quercus*, s.s.), which are the canopy dominants or co-dominants in all of the warm-temperate deciduous forest regions. Oaks are apparently well adapted to these climates, perhaps because their somewhat thicker, more reinforced leaves (usually with a distinct cuticle) permit exploitation of the margins (especially autumn) of the potentially longer growing season. Canopy trees in these transitional forests are largely deciduous, but understoreys (and occasionally canopies) may have evergreen elements. In Japan, the warm-temperate deciduous forest zone was conceived as occupied mainly by deciduous *Quercus* forests, and a

Castanea crenata-Quercus serrata association was recognized in central Honshū (Karizumi 1956). Major warm-temperate deciduous species in East Asia include *Q. acutissima*, *Q. aliena*, *Q. serrata* and *Q. variabilis*, plus *Q. wutaishanica* (s.l.) in China (see also Menitsky 2005 for all Asian oaks).

In eastern North America, some tree species span the entire north-south range of deciduous forests, including *Fagus grandifolia*, *Quercus alba* and *Q. rubra*, several *Carya* species, and *Acer rubrum*. Other species have distinctly "northern" or "southern" ranges, in genera including *Quercus*, *Acer*, *Fraxinus* and *Tilia* (cf Daubenmire 1978). For example, *Quercus rubra* (northern red oak) is replaced southward by *Q. falcata* (southern red oak). Many other such examples of northern and southern species can be found among the range maps of Little (1971–1978). The same is true of *Fagus*, *Quercus*, and some other deciduous tree genera in Japan. Even so, there appear to be few real vicariant oak species between East Asia and eastern North America. *Q. aliena* is called 'Oriental white oak' in English but has a much more limited north-south range than 'white oak' (*Q. alba*) in eastern North America. Furthermore, many of the warm-temperate deciduous candidates in eastern North America, including *Q. coccinea*, *Q. falcata* and *Q. velutina*, are in the red-oak group *Erythrobalanus*, which is endemic to the Western Hemisphere (see Miller and Lamb 1985 for North American oaks). *Liquidambar styraciflua* also seems to be a good warm-temperate deciduous candidate in eastern North America (cf *L. formosana* in southeastern China).

In Europe, the two main oak species over much of the continent are *Quercus robur* and *Q. petraea*, the ranges of which overlap widely except for the extension to the Ural Mountains by *Q. robur*. If the climatic envelope of *Q. petraea* is projected onto eastern North America, it spans the typical temperate and warm-temperate deciduous areas, almost as widely as does *Q. alba* (Box and Manthey 2006). This, and its range in Europe, both suggest that Q. *petraea*, like *Q. alba*, is not exclusively a warm-temperate deciduous species, although both can function as such (see also Pedrotti herein). *Q. pubescens*, on the other hand, and despite its complicated taxnomy (see Guarino et al. herein;Wellstein and Spada herein), seems to be a true warm-temperate deciduous species, along with other candidates such as *Q. cerris*, *Q. pyrenaica*, *Q. faginea*, and *Q. frainetto*. The climatic envelopes of these species generally project onto eastern North America as "southern" species, as shown in Fig. 2 for *Q. pubescens*. Mosaics involving *Q. robur* and the more southern *Quercus* species are described from Portugal by Costa et al. (herein). Geographic distribution types of Mediterranean-central European taxa were described by Jäger (1970).

Several features of deciduous oaks can be seen as possible adaptations to the intermediate position of warm-temperate deciduousness. One such feature is marcescence, by which trees (mainly oaks) retain withered brown leaves through the winter (e.g. *Q. pubescens*, *Q. pyrenaica*, *Q. faginea*). This may have functional value in submediterranean climates, as explained by García-Mijanos et al. (herein) and commented on by other authors in this book. Another possible adaptation, in the southeastern USA, is the "tardy deciduousness" shown by *Quercus nigra* and *Q. phellos*, whose leaves do not turn completely brown and drop (if at all) until December. These two species have entire leaves, however, like most evergreen oaks, and may represent a more truly transitional position between evergreenness and deciduousness. Finally, irregular or incomplete deciduousness has also been suggested as a more general characteristic of some deciduous oaks, including semi-deciduous *Q. canariensis* and even *Q. suber* (cork oak, normally considered evergreen) in some Mediterranean areas (see Schirone et al. herein). Sclerophylly and semi-deciduousness were interpreted by Sánchez de Dios et al. (2009) as mediterranean features, marcescence as submediterranean, and truly deciduous leaves as Euro-Siberian, i.e. nemoral. (Note that the marcescent oaks are called semi-deciduous, however, by del Río and Penas 2006, and probably also by some others.) The spread of deciduous oaks in Europe since the last glaciation has been summarized by Brewer et al. (2002).

Evergreenness versus deciduousness is essentially a functional tradeoff involving the potentially higher photosynthetic rates of malacophyllous deciduous leaves versus the potentially longer growing season of evergreen leaves. This calculus is tempered, though, by several other factors, such as the greater nutrient requirements for building deciduous leaves; the extra energy storage required to do this each spring (before photosynthetic gains can be realized); the potentially longer lifespans and water-loss control of evergreen leaves; and the inhibition at low temperatures of the water uptake needed by evergreens in winter (e.g. Chabot and Hicks 1982; Aerts 1995; Givnish 1986, 2002; Villar and Merino 2001). Such 'physiological drought' can occur at low but above-freezing temperatures and may mark the northern limit, for example, of "southern pines" in the eastern USA (Hocker 1956). Of course, climatic winter dryness may limit many evergreen trees on their tropical side, as in the monsoonal climates of south and southeast Asia. Insights into physiological advantages of evergreenness versus deciduousness have been given recently, among many others, by Cavender-Bares et al. (2005) and by Baldocchi et al. (2010). Growth and phenological patterns have been explained by Tessier et al. (1994) and by Dhaila et al. (1995); topographic effects have been demonstrated by Isogai (1994). Particular advantages of evergreenness have been summarized by Aerts (1995) and of deciduousness in mediterranean environments by Blumler (1991). A general

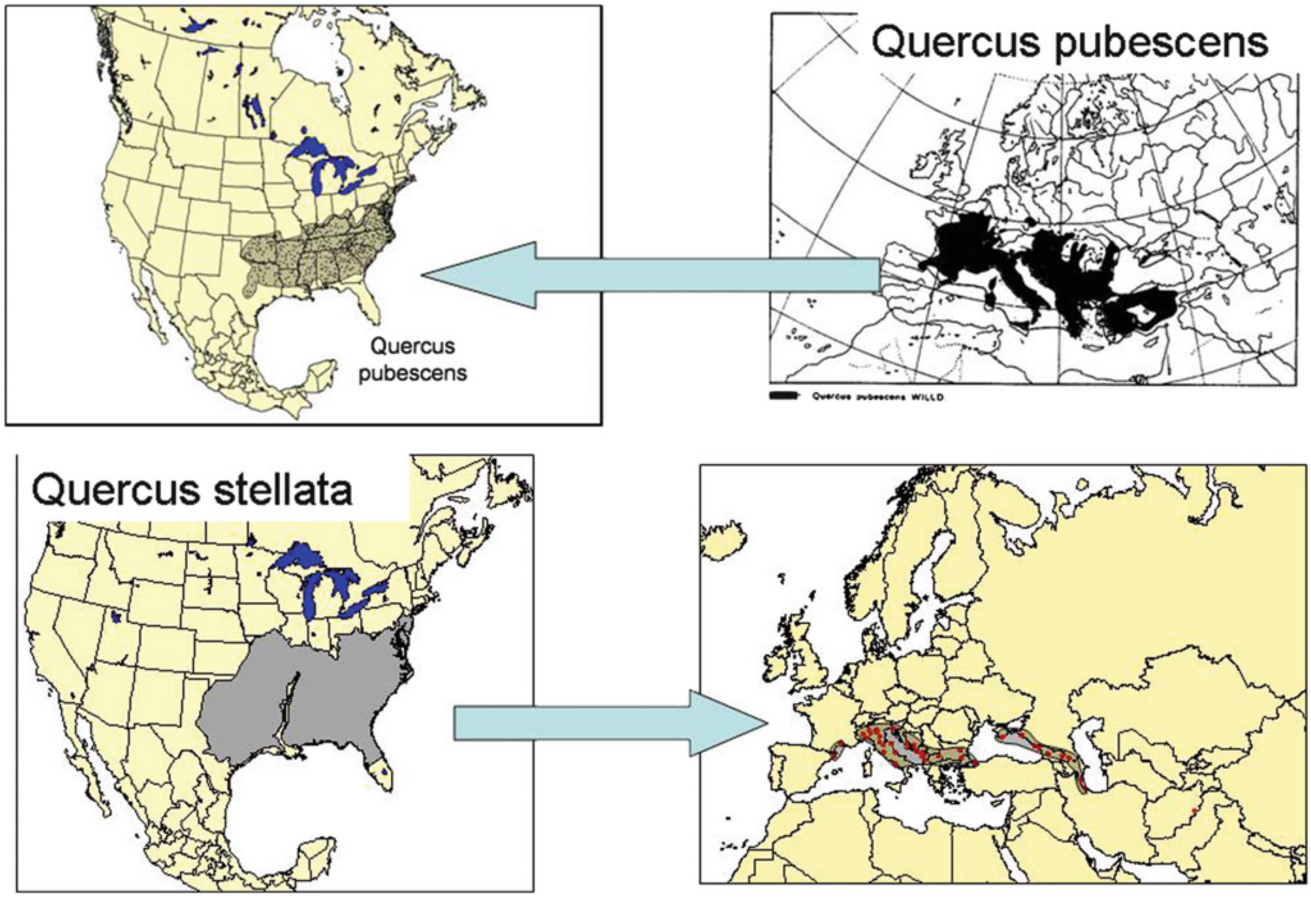

Fig. 2 Cross-projections of oak species between Europe and eastern North America. The top portion shows *Quercus pubescens* from mainly southern Europe. When its climatic envelope is projected onto North America, it appears as a largely "southern" species, corroborating its designation as perhaps the quintessential warm-temperate deciduous species of Europe. The bottom portion shows *Quercus stellata*, which spans the typical and warm-temperate regions in eastern North America but co-dominates only in drier areas further west (Missouri, eastern Oklahoma, eastern Texas). The projection of its climatic envelope onto Europe covers only a small area, coinciding with areas often called submediterranean. This projection of climatic envelopes is explained in Box and Manthey (2006), where other cross-projections are also shown

"solution" to the "triple paradox" of evergreen versus deciduous leaves has been proposed by Givnish (2002). Some of these ideas and other relative advantages and disadvantages of evergreen versus deciduous habits are listed in Table 6 and will be discussed by other authors in this book.

5 Vegetation Boundaries in Temperate Forest Regions

Hypothesized regions of warm-temperate deciduous forest and their main canopy tree species were shown in Table 5. These include not only East Asia and the southeastern USA but also some deciduous forests in warmer areas of southern Europe and in the Middle East, and perhaps even North Africa. Such forest regions should be recognizable by vegetation boundaries as well as by climatic conditions.

In Japan there is a clear difference between cool-temperate (into typical temperate) regions dominated by *Fagus* or by *Quercus crispula* (= *Q. mongolica* var. *grosseserrata*) to the north and more southern regions where deciduous forests are dominated by other oak species, especially those that may be replaced eventually by evergreen (broad-leaved) trees in the warm-temperate zone. These latter oaks include *Q. serrata*, *Q. variabilis*, *Q. aliena*, and *Q. acutissima*. In Manchuria and parts of northern China there is also a cool-temperate (to typical temperate) region of dominance by *Q. mongolica* (*s.s.*) and a region to the south (across north-central China) involving the same group of "warm-temperate" oaks as in Japan, plus *Q. wutaishanica* (which now includes *Q. liaotungensis*). These regions have been identified from extensive fieldwork and are shown on the map by Fujiwara and Harada (herein; cf Fujiwara et al. 2008; You et al. 2008). A recent attempt has been made (Zhao and Tian 2001; cf Wu and Raven 1999) to combine

Table 6 Advantages and disadvantages of deciduousness

Advantages	
Dropping leaves avoids water loss in unfavorable season: cold winter or tropical dry season; may also permit evasion of late-summer drought (if enough reserves stored)	
Softer leaves (malacophylls), with higher gas-exchange rates: thus higher photosynthesis and potential growth rates (may be especially important for establishment of young plants)	
Leaflessness reduces water loss in winter/dry season, leaving more water in soil for beginning of growing season	
Malacophylls are generally more shade-tolerant, so deciduous can grow up under sclerophylls and conifer (coriaceous) and replace them	
Disadvantages	
Deciduous plants are not "present" at beginning of the growing season and may lose their space to evergreens	
Deciduous plants must produce new leaves each year and thus do not use the whole growing season for positive photosynthesis and net growth	
Malacophylls require more nutrients to build, especially nitrogen, than do most evergreen leaves, which are lignin-rich but nutrient-poor	
Malacophylls decompose faster and may facilitate faster net loss of nutrients from systems	
Soft malacophylls need more water than "harder" evergreen leaves (except laurophylls)	
Malacophylls are generally intermediate in shade tolerance and so can be replaced by highly shade-tolerant laurophylls	

For more consideration of the advantages and disadvantages of the deciduous versus evergreen habit, see *inter alia*, Baldocchi et al. 2010; Sánchez de Dios et al. 2009; Cavender-Bares et al. 2005; Givnish 2002; Damesin et al. 1998; Zobel and Singh 1997; Aerts 1995; Dhaila et al. 1995; Isogai 1994; Tessier et al. 1994; Blumler 1991; Meusel and Jäger 1989; Monk 1966.

these last two taxa with *Q. mongolica* into a single species, but this may not have considered their ecological differences sufficiently.

In eastern North America, the major discontinuity is suggested graphically by a figure (from Daubenmire 1978, pp. 121, 132) that depicts typical ranges for "northern" tree species such as *Acer saccharum* (sugar maple, as on the Canadian national flag) versus "southern" species such as *Q. laurifolia* (more evergreen in the southern part of its range). The southern deciduous forests have been called the Oak-Hickory-Pine region (Braun 1950), 'southern mixed hardwoods' (Quarterman and Keever 1962), 'warm-temperate mixed forests' (Lieth 1975), and the 'deciduous-evergreen-coniferous region' (Greller 1989). Some "southern" deciduous species also reappear disjunctly in montane belts of the Sierra Madre Oriental of eastern Mexico, where they can be almost evergreen (Rzedowski 1978; Velázquez et al. 2000; cf Borchert et al. 2005). Warm-temperate deciduous and evergreen woods overlap in many places, including central Texas (van Auken et al. 1981).

In southern Europe, deciduous forests in warmer areas have been called 'thermophilous' (e.g. Dimopoulos et al. 2005; Čarni et al. 2009) or, where summers are drier, 'submediterranean' (e.g. Schmithüsen 1968; Meusel and Jäger 1989; Sánchez de Dios et al. 2009). In Europe, the major discontinuity in deciduous forests is between forests of *Fagus sylvatica* or *Q. robur* to the north and the more southern deciduous forests dominated mainly by *Q. pubescens*, *Q. cerris*, or *Q. petraea* (or by *Q. broteroi* or *Q. pyrenaica* in Iberia, by *Q. frainetto* in the Balkans, or by *Q. iberica* in Georgia). The idea that these species are more "southern" or thermophilous was corroborated by projecting their climatic envelopes onto eastern North America, where they coincided largely with the ranges of "southern" American species (see Fig. 2; Box and Manthey 2006). The main regions of these warmer-climate deciduous forests in southern Europe are across northern Iberia (where not too dry); from submediterranean southern France to Insubria and southward into interior peninsular Italy; in lower and more southern parts of the Balkan Peninsula; and in small areas of the Euxine-Hyrcanian region. In these areas, the deciduous oak forests involving species other than *Q. robur* are to be found especially on south-facing slopes (Franco Pedrotti, personal communication). Perhaps the most detailed description of Balkan thermophilous forest, with phyto-sociological tables, has been given in the recent book on *Forest Vegetation of the Galičica Mountain Range*, in Slavic northern Macedonia, by Matevski et al. (2011).

6 Recognizing Temperate Climatic Subregions

Most of the climatic factors that limit regional ranges of warm-temperate deciduous trees involve aspects of temperature, especially winter mean temperatures and absolute minima (cf Wolfe 1979). The ranges of putative warm-temperate deciduous species also correlate with summer mean temperatures, although this apparent threshold effect may be only a surrogate for the longer warm period. In some cases forests are limited by drier conditions, usually toward continental interiors. Where winters become milder in East Asia, the deciduous trees are simply replaced by evergreen (broad-leaved) tree species. In Manchuria and northern Japan (and upward in mountains), warm-temperate deciduous trees are limited mainly by cooler, shorter summers (but also in some cases by colder winters). In the southeastern USA, the situation is similar except that winter mean temperatures are much higher than at the same latitudes in East Asia and there is never any persisting snow cover. Evergreen broad-leaved trees are precluded in the southeastern USA mainly by unusual low-temperature events (Box 1995 and herein). Even so, warm-temperate deciduous trees also occur much less where extremes go below about −24°C. Finally, the higher latitude and windward west-side position of Europe mean that its summers are somewhat cooler than in East Asia or eastern North America. These relationships, for selected temperate-zone sites, can be seen from the climatic data in the Appendix at the end of this book.

Along temperature gradients from north to south, areas of relatively rapid temperature increases may also suggest climatic boundaries. Identifying such climatic "breaks" can be useful, especially since quantitative values for climatic variables will be necessary for modeling and mapping climatic regions. Climatic data for representative sites in the three main temperate forest regions of the Northern Hemisphere are given in Tables 7, 8 and 9. The data include temperature levels, values of Kira's Warmth and Coldness Indices, the number of consecutive warm months (mean above 10°C), and the annual climatic moisture balance (precipitation versus potential evapotranspiration). The three main deciduous forest regions are considered below, with the sites in Tables 7, 8 and 9 also showing the climate type suggested.

(a) **East Asia**

In Japan (see Table 7: top section of sites), southern Hokkaidō is significantly warmer than most of the island, which does not reach 21°C for the warmest month (Tmax), has only 4–5 warm months (Lwarm), and has much colder winters (cf Tmin and Tabmin). There is an even larger "break", though, between southern Hokkaidō and the northern tip of the main island Honshū, where warm-month mean temperatures immediately exceed 23°C, there are at least 6 warm months, and WI exceeds 70 (and soon exceeds Kira's threshold of 85 for warm-temperate). Another "break" appears in central Honshū, at around 25°C for Tmax, south of which there are at least 7 warm months, mean January temperature is above freezing, and WI exceeds 100, except at inland sites like Nagano (which was Kira's prototype for warm-temperate deciduous). Taken together with vegetation patterns, these thresholds suggest the following scheme:

- Cool-temperate if Tmax is below 22°C (perhaps 21°C), WI is below 60, only 4–5 months are warm (mean above 10°C), and winter mean temperatures are well below freezing; this is the zone of *Quercus crispula* woods (*Q. mongolica* var. *grosseserrata*) over most of lowland Hokkaidō (although with no *Fagus*) and corresponds to the mainland zone of *Q. mongolica* with *Pinus koraiensis*;
- Typical temperate if Tmax is above 22°C but below 25°C, WI is > 60 and there are 6 warm months but cold-month means are still below freezing (e.g. Hakodate, Aomori, Sendai); this is the zone of *Fagus* forests over southernmost Hokkaidō and most of lowland Tōhoku (northern half of Honshū), including also the lower and middle elevation of mountains; and
- Warm-temperate if Tmax approaches or exceeds 25°C, WI is above Kira's threshold of 85 (mostly above 90 or more), at least 7 months are warm, and winter monthly mean temperatures are generally above freezing; this is the zone of evergreen broad-leaved forests dominated by various *Castanopsis* spp and *Machilus* (*Persea*) *thunbergii* – except for sites like inland Nagano, where Tmin is still below freezing.

Let us compare this scheme with the other regions.

In Manchuria (Russian Far East, Heilongjiang, and northernmost Korea), Tmax is < 22°C, WI is < 60, only 4–5 months are warm, and Tmin is far below freezing, generally below -15°C; this is the cool-temperate mixed forest zone with *Quercus mongolica*, often *Pinus koraiensis*, and species-rich mesophytic forests of "Manchurian species" where the climate is truly humid (cf Box and Fujiwara 2013).

In peninsular Korea Tmax is generally < 25°C in the north and > 25°C in the middle and south, with WI, warm months and winter mean temperatures generally following the patterns suggested above. This divides peninsular Korea into a typical-temperate north and middle, with deciduous *Quercus* forests (still recovering slowly from the Korean War); and a warm-temperate deciduous south, with *Q. serrata*, *Q. variabilis*, and other typically warm-temperate oaks, as in Japan and China. Only the south-coastal strip is warm-temperate evergreen (e.g. Pusan), where mean cold-month temperatures are above freezing and the absolute minimum does not go below about -15°C.

In northeastern China, most of Jilin and Liaoning have Tmax > 22°C, with at least 5 warm months, and so can be called typical temperate; *Q. mongolica* still occurs here, but other oaks also appear as one goes southward. Southernmost Liaoning is already much less severely cold in the winter and summers become warmer (WI > 85, usually 6 warm months), with Tmax surpassing 25°C (and with 7 warm months) in Shandong, around Beijing, and westward through Shanxi and Shaanxi (cf Xian); this is a region of warm-temperate deciduous oak forests (e.g. Wu et al. 1980, Chen 1995; Fujiwara et al. 2008). *Q. mongolica* occurs throughout most of northern China and has been considered both a cool-temperate and typical-temperate species (Box and Fujiwara 2013). Finally, southern China has Tmax generally > 27°C, at least 8 warm months, WI > 120, and mean winter temperatures above freezing; this is the region of evergreen broad-leaved forests, which appear climatically to be warm-temperate (WI below Kira's 180 threshold and

Table 7 Climatic data and interpreted climate types for selected sites in East Asia

	Lat	Elev	Tmax	Tmin	Tabmin	WI	CI	Lwarm	MIy	Type
Asahikawa (Hokkaidō)	43.8	114	20.8	−9.2	−41.0	60	−50	5	2.01	Cool
Sapporo (SW Hokkaidō)	43.0	17	21.4	−5.5	−28.5	65	−35	6	1.91	Typical
Hakodate (S peninsula)	41.8	33	21.9	−3.7	−21.7	68	−27	6	2.00	Typical
Aomori (N tip Honshū)	40.8	3	23.5	−2.7	−24.0	79	−23	6	2.22	Typical
Sendai (N Pacif Honshū)	38.3	39	24.7	0.7	−20.2	94	−10	6	1.74	WT-decid
Yamagata (N Honshū)	38.3	153	25.1	−1.4	−20.0	93	−18	6	1.81	WT-decid
Nagano(central Honshū)	36.7	418	25.6	−1.3	−17.0	98	−16	7	1.41	WT-decid
Tōyama (Japan Sea side)	36.7	9	26.5	2.0	−13.1	110	−5	8	2.90	EG-BL
Yokohama (Tōkyō Bay)	35.4	39	26.5	4.6	−8.2	120	−0.5	8	1.92	EG-BL
Kyōto(Kansai)	35.0	41	26.8	2.9	−11.9	114	−3	8	1.87	EG-BL
Blagoveshchensk (Amur)	50.3	132	21.5	−23.9	−45.0	57	−114	5	0.97	Cool
Hailar (Khingan Mtns)	49.2	650	20.2	−27.3	−49.3	50	−134	4	0.69	Cool
Khabarovsk (Amur)	48.5	86	21.2	−21.8	−43.0	59	−100	5	1.11	Cool
Harbin (Heilongjiang)	45.7	151	23.1	−19.6	−42.4	69	−87	5	0.92	Typical
Nikolsk-Ussuriysk (Prim)	43.8	46	21.1	−19.8	−36.8	59	−85	5	1.16	Typical
Vladivostok (Primorye)	43.1	138	20.3	−13.7	−31.0	56	−63	4	1.39	Cool
Hyesan (NE Korean mtns)	41.4	714	20.6	−16.7	−35.8	58	−74	5	1.13	Cool
Kimchaek (NE coast)	40.7	19	22.1	−5.8	−23.8	70	−33	6	1.21	Typical
Pyongyang (N peninsula)	39.0	36	24.3	−7.8	−30.0	90	−36	6	1.40	Typical
Seoul AP (mid-peninsula)	37.6	18	25.3	−3.6	−24.4	100	−21	7	1.92	WT-decid
Pusan (S Korea)	35.1	69	25.8	2.4	−14.0	113	−4	8	1.75	EG-BL
Shenyang (Liaoning)	41.8	45	24.7	−12.3	−33.1	87	−55	5	1.09	Typical
Dalian (S Liaoning)	38.9	97	24.2	−5.0	−21.1	92	−28	6	0.92	Typ/WT-d
Beijing	39.9	52	26.1	−4.5	−27.4	107	−25	7	0.83	WT-decid
Qingdao (Shandong)	36.1	79	25.2	−1.3	−17.6	101	−15	7	0.95	WT-decid
Xuzhou (N Jiangsu)	34.3	4	27.3	−0.2	−18.3	122	−11	7	0.93	WT-decid
Xian (Shaanxi)	34.3	412	27.0	−0.6	−20.6	116	−12	7	0.72	WT-decid
Nanjing (Jiangsu)	32.0	15	27.9	2.3	−13.8	129	−4	8	1.11	EG-BL
Shanghai	31.2	12	27.6	3.3	−12.1	128	−2.3	8	1.25	EG-BL
Wuhan (Hubei)	30.6	23	28.9	3.5	−13.0	141	−1.5	9	1.23	EG-BL
Fuzhou (Fujian)	26.1	20	29.0	11.1	−6.0	180	0	12	1.17	EG/Subtrop
Guangzhou (Guangdong)	23.1	18	28.5	13.5	−2.0	203	0	12	1.29	Subtrop
Chengdu (Sichuan)	30.7	498	25.8	5.8	−6.0	137	0	9	0.99	EG-BL
Chongqing (W-central)	29.6	259	29.2	8.1	−3.1	165	0	9	0.99	EG-BL
Kunming (Yunnan)	25.0	1893	19.9	8.4	−7.0	119	0	10	1.12	EG-BL
Simao (S Yunnan plateau)	22.8	1300	22.5	12.8	−2.5	163	0	12	1.35	Subtrop

Climate types are interpreted, based on apparent threshold values in the data:
Cool = Cool-temperate (deciduous, with Tmax < 21°C)
Typical = Typical temperate (deciduous, with Tmax ≥ 21°C)
WT-decid = Warm-temperate deciduous (with Tmax > 24°C; at least 6, usually 7 warm months)
EG-BL = Warm-temperate evergreen (with Tabmin ≥ −15°C but lower Tmax threshold, as at Kunming)
Subtrop = Subtropical (with Tabmin ≥ −3°C but also a lower Tmax threshold, as at Simao)
Other abbreviations:
Lat = latitude
Elev = elevation (m)
Tmax (Tmin) = mean temperature of warmest (coldest) month (°C)
Tabmin = absolute minimum temperature (°C, coldest ever measured; ! = estimated lower)
WI (CI) = Kira's warmth (coldness) index
Lwarm = number of consecutive warm months (monthly means > 10°C)
MIy = annual moisture index (precipitation / potential evapotranspiration)

absolute minima still below about -3°C) until one reaches Guangdong, perhaps southern Fujian, and the lowlands south of the Yunnan Plateau. In China, unlike Florida, there is not enough information to show a clear discontinuity between the temperate flora of the warm-temperate zone and the (sub)tropical flora of the subtropical zone.

Table 8 Climatic data and interpreted climate types for selected sites in Eastern North America

	Lat	Elev	Tmax	Tmin	Tabmin	WI	CI	Lwarm	MIy	Type
Québec (SE Québec)	46.8	90	19.5	−11.8	−36.7	54	−64	5	2.15	Cool
Montréal (S Québec)	45.5	57	21.2	−9.9	−33.9	67	−51	5	1.77	Typical
Boston, Massachusetts	42.4	6	21.8	−2.6	−27.8	76	−23	6	1.73	Typical
Hartford, Connecticut	41.9	53	23.0	−3.5	−32.2	84	−24	6	1.73	Typical
New York (city)	40.8	39	24.3	−0.4	−26.1	95	−15	7	1.62	Typ/WT-d
Baltimore, Maryland	39.3	4	25.7	1.5	−21.7	110	−8	7	1.35	WT-decid
Charlottesville, Virg.	38.0	265	24.7	2.0	−23.3	110	−7	7	1.45	WT-decid
Raleigh-Durham, N Car.	35.9	132	25.6	4.7	−22.8	123	−0.3	9	1.28	WT-decid
Columbia, S Carolina	34.0	74	27.1	7.9	−18.9	152	0	9	1.08	WT-decid
Athens, Georgia	33.9	246	26.5	5.7	−20.0	138	0	9	1.27	WT-decid
Cape Hatteras, N Carol.	35.3	2	25.6	7.7	−14.4	140	0	9	1.44	EG-BL
Charleston, S Carolina	32.8	3	27.7	10.1	−12.2	168	0	12	1.09	EG-BL
Savannah, Georgia	32.1	15	27.6	10.5	−16.1	171	0	12	1.08	EG-BL
Pensacola (NW Florida)	30.5	36	27.5	11.4	−15.0	179	0	12	1.30	EG-BL
Gainesville (N Florida)	29.6	29	27.3	12.7	−14.4	187	0	12	1.08	EG-BL
Tampa (mid-Gulf Florida)	28.0	8	27.9	15.9	−7.8	206	0	12	0.96	EG-BL
Miami (S Florida)	25.8	3	28.2	19.8	−2.8	231	0	12	1.03	Subtrop
Banner Elk (N Carolina)	36.2	1143	19.1	0.5	−35.0	70	−12	6	2.20	Cool
Bluefield (W Virginia)	37.3	881	21.3	−0.7	−29.4	86	−13	7	1.48	Typical
Toronto (Ontario)	43.7	116	20.8	−5.1	−32.8	67	−35	5	1.40	Cool
Madison, Wisconsin	43.1	263	22.4	−8.2	−38.3	76	−43	6	1.29	Typical
Pittsburgh, Pennsylvania	40.5	367	23.2	−1.1	−30.0	90	−16	7	1.36	Typical
Indianapolis, Indiana	39.7	243	24.0	−2.9	−32.8	94	−19	7	1.46	Typ/WT-d
Cincinnati, Ohio	39.1	232	24.5	−1.4	−27.2	103	−15	7	1.42	WT-decid
Kansas City, Missouri	39.3	312	25.7	−2.5	−30.6	101	−18	7	1.28	WT-decid
St.Louis, Missouri	38.7	174	26.3	−0.4	−30.6	112	−13	7	1.24	WT-decid
Lexington, Kentucky	38.0	298	24.6	0.5	−29.4	105	−10	7	1.49	WT-decid
Nashville, Tennessee	36.1	180	26.7	4.3	−27.2	129	−0.7	8	1.28	WT-decid
Little Rock, Arkansas	34.7	78	27.7	3.9	−25.0	139	−1.1	9	1.31	WT-decid
Oxford, Mississippi	34.4	116	26.7	5.2	−25.0	137	0	9	1.39	WT-decid
Montgomery, Alabama	32.3	67	27.6	8.1	−20.6	160	0	10	1.23	WT-decid
Mobile, S Alabama	30.7	66	27.3	10.6	−18.3	173	0	12	1.40	WT-decid
Biloxi, S Mississippi	30.4	5	27.8	10.9	−17.2	177	0	12	1.31	EG-BL
Baton Rouge, Louisiana	30.5	20	27.8	11.3	−16.7	180	0	12	1.25	EG-BL
Tulsa, Oklahoma	36.2	206	28.5	2.2	−26.7	133	−4	8	1.06	WT-decid
Dallas, N Texas	32.8	134	30.0	7.2	−22.2	168	0	9	0.82	WT-decid
Austin, central Texas	30.3	193	29.3	9.7	−18.9	182	0	11	0.68	WT-decid

Climate types are interpreted, based on apparent threshold values in the data:
Cool = Cool-temperate (deciduous, with Tmax < 21°C)
Typical = Typical temperate (deciduous, with Tmax ≥ 21°C)
WT-decid = Warm-temperate deciduous (with Tmax > 24°C; generally at least 7 warm months)
EG-BL = Warm-temperate evergreen (with Tabmin ≥ -15°C but lower Tmax threshold)
Subtrop = Subtropical (with Tabmin ≥ -3°C but also a lower Tmax threshold)
The other abbreviations are as in Table 7. Sites are grouped, generally from north to south, within the following regions: north Atlantic, middle and south Atlantic, southern Appalachians, northern interior, interior South, and southern Plains

(b) **Eastern North America**

On the east side of North America, climatic patterns (see Table 8) are much the same at corresponding latitudes as in East Asia. In the northern Atlantic area, the main break comes at around Tmax = 22°C, which separates eastern Canada and northern New England to the north (WI $<$ 85) from the more moderate climates of southern New England, with their longer warm periods (6–7 months) and warmer summers (WI $>$ 85). Eastern Canada and northern New England are areas of deciduous "northern hardwood" forests, especially with *Acer saccharum*, and mixed forests with admixtures of *Pinus strobus* (five soft needles, cf *P. koraiensis*), plus other more northern taxa such as *Q. rubra* and *Betula* spp. (see, for example, Barbour and Billings 1988). Southern New England already has significantly more tree

Table 9 Climatic data and interpreted climate types for selected sites in Europe

	Lat	Elev	Tmax	Tmin	Tabmin	WI	CI	Lwarm	MIy	Type
Uppsala (Sweden)	59.9	21	16.6	−4.6	−39.5	42	−40	4	1.08	Cool
Greenwich (London)	51.5	7	17.1	4.0	−14.1!	61	−1.9	6	0.98	Cool
Krakow (S Poland)	50.1	213	19.4	−3.0	−26.6	66	−23	5	1.06	Cool
Paris-Le Bourget	49.0	66	18.7	2.6	−17.0	72	−5	7	0.94	Cool
Wien (Vienna, E Austria)	48.2	203	19.6	−1.4	−22.6	71	−17	5	1.02	Cool
Dijon (Bourgogne)	47.3	222	19.8	1.7	−22.0	73	−8	6	1.10	Cool
Genève (W Switzerland)	46.2	416	18.7	−0.6	−18.4	62	−14	5	1.46	Cool
Lyon (Rhône/France)	45.7	200	20.5	2.1	−24.6	79	−7	7	1.18	Cool
Toulouse (S France)	43.6	152	21.2	4.6	−19.2	91	−0.4	7	0.92	Typical
Avignon (Rhône/S France)	43.9	20	23.4	5.2	−16.0	107	0	7	0.75	Mediterr
Nice (Provence)	43.6	4	22.9	7.3	−7.5	118	0	9	0.92	Mediterr
Marseille (Provence)	43.4	6	22.8	6.5	−16.8	111	0	8	0.69	Mediterr
Barcelona (Catalonia)	41.4	175	24.3	9.2	−6.7	135	0	11	0.62	Mediterr
Trento (NE Italy)	46.1	312	22.8	0.8	−16.5!	97	−8	7	1.35	Thermoph
Torino (NW Italy)	45.2	301	22.7	0.2	−16.2!	92	−10	7	1.22	Thermoph
Milano (N Italy)	45.4	107	23.9	1.1	−16.2!	100	−8	7	1.31	Thermoph
Firenze (Toscana)	43.8	40	24.9	5.4	−10.6	116	0	8	0.97	WT-d/Med
Roma	41.9	45	25.0	6.7	−5.4	125	0	9	0.91	Mediterr
A Coruña (Galicia)	43.4	58	18.8	10.2	−5.5	109	0	12	1.20	Cool
Vitoria (N Spain)	42.8	550	19.2	4.7	−17.8	79	−0.3	6	1.29	Cool
Burgos (N meseta)	42.4	894	18.8	2.4	−22.0	67	−6	6	0.92	Cool
Bragança (N Portugal)	41.8	691	21.2	4.6	−12.0	87	−0.4	7	1.02	Typical
Salamanca (meseta)	41.0	782	21.6	3.9	−18.1!	86	−1.5	7	0.57	Dry Temp
Segovia (central mtns)	40.9	1005	21.5	3.2	−13.2	82	−3.4	6	0.72	Typical
Madrid (meseta)	40.4	657	24.8	5.0	−10.1	107	0	7	0.52	Dry WT
Cuenca (meseta)	40.1	945	22.1	3.6	−17.8	85	−2.3	6	0.77	Typical
Lisboa (W Portugal)	38.7	95	22.0	10.6	−1.7	132	0	12	0.74	Mediterr
Evora (central Portugal)	38.6	321	23.9	8.9	−3.6	129	0	10	0.68	Mediterr
Cluj-Napoca (Transylvania)	46.8	410	19.2	−4.4	−29.8	66	−27	5	0.98	Cool
Ljubljana (Slovenia)	46.2	385	19.2	−1.1	−23.0	68	−17	6	2.32	Cool
Zagreb (Croatia)	45.8	163	21.4	−0.1	−30.5	85	−11	7	1.31	Typical
Beograd (Serbia)	44.8	132	22.1	−0.2	−25.5	91	−11	7	0.94	Typical
Bucuresti (Romania)	44.4	82	22.9	−2.9	−30.0	89	−19	7	0.85	Thermoph
Split (Dalmatian coast)	43.5	122	25.6	7.4	−11.4!	132	0	9	0.87	Mediterr
Plovdiv (Bulgaria)	42.1	179	23.3	1.0	−31.5	97	−8	7	0.72	Thermoph
Skopje (N Makedonia)	42.0	238	23.3	0.3	−25.0	97	−10	7	0.71	Thermoph
Istanbul (NW Türkiye)	41.0	40	23.6	5.4	−16.1	110	0	8	0.83	WT-d/Med
Ioannina (NW Greece)	39.7	466	24.7	5.1	−10.0	113	0	8	1.41	WT-d/Med
Moskva (central Russia)	55.7	156	18.5	−10.2	−42.0	50	−59	5	1.13	Cool
Kyyiv (Kiev, Ukraine)	50.4	180	20.5	−5.5	−40.0	69	−37	5	0.97	Cool
Rostov-na-Donu (S Russ)	47.2	77	23.0	−5.4	−33.0	82	−34	5	0.81	Typical
Yalta (S Crimea)	44.5	14	23.7	3.8	−14.5	98	−2.3	7	0.71	WT-d/Med
Zakataly (Azerbayjan)	41.6	500	24.8	2.9	−22.0	103	−5	7	1.27	WT-decid

Climate types are interpreted, based on apparent threshold values in the data:
Cool = Cool-temperate (deciduous, with Tmax < 21°C)
Typical = Typical temperate (deciduous, with Tmax ≥ 21°C)
Thermoph = Thermophilous (i.e. warmer-deciduous but with Tmax near only 23°C)
WT-decid = Warm-temperate deciduous (with Tmax above 23°C)
Mediterr = Mediterranean, i.e. essentially EG-BL but dry summer or dry year-round (not necessarily forest)
Dry Temp = Typical temperate but too dry for forest (MIy < 0.6); similarly for Dry WT (dry warm-temperate)
Other abbreviations are as in Tables 7 and 8. Exclamation marks with Tabmin mean the measured value (perhaps over only a few years) was replaced by a lower estimate (see Methodology section of main text)

species, including some with more southern ranges. In the middle and south-Atlantic region, Tmax is generally > 25°C, WI is >110, there are at least seven warm months, and Tmin is > 0°C, meaning that there is no persistent winter snow cover. From the South Carolina coast on southward, all 12 months can be above 10°C. This is a region of "southern hardwood" forests, especially so-called oak-hickory (*Quercus-Carya*) forests, with persistent, secondary "southern pines" (called 'heliophilic' by Box 1981). These southern forests correspond very well to the warm-temperate deciduous forests of East Asia, in climatic parameters as well as in vegetation structure and main tree taxa (see Box, herein - a).

In the Appalachians, patterns follow elevation (cf Greller 1988). Above the lowland warm-temperate deciduous forests in the South, on the (leeward) Atlantic side, are more typical-temperate foothill and lower-montane forests, originally with much *Castanea dentata* but now (after decimation by the chestnut blight) with co-dominance by *Quercus prinus*, *Q. alba* and *Q. rubra*. This is the Oak-Chestnut forest of Braun (1950). On the wetter western side are the richest forests, the Mixed Mesophytic Forest of Braun, with no dominant species but as many as 10 canopy co-dominants, sometimes reaching more than 40 m in height (cf Bluefield in Table 8). Above this is a belt of truly montane, cool-temperate mixed forest (cf Banner Elk) involving mainly "northern hardwoods", *Pinus strobus* (not originally native to the southern Appalachians), and some admixtures of the two local subalpine conifers, especially *Picea rubens* (as in eastern Canada) plus endemic *Abies fraseri* at higher elevations.

In the interior lowland (between the Appalachians and the drier Great Plains), zonation is much the same but with more continental temperature regimes. In the north, Toronto (on Lake Erie) has Tmax < 21°C but most other sites are above 22°C, with WI > 70 and have at least 6 warm months (to 7 in the Ohio River valley); Tmin is always below 0°C, though, and there is often a persistent winter snow cover (at least before global warming). This region has *Acer-Tilia* forests (especially Wisconsin) and *Fagus-Acer* forests (especially Ohio), plus more continental oak-hickory forests further west (e.g. Missouri; see Braun 1950 or Box, herein - a). South of the Ohio River, Tmax is generally 26–28°C, WI exceeds 100, at least 7 months are warm, and there is no winter snow cover (Tmin > 0°C). This is a large region of warm-temperate deciduous forest, including the Western Mesophytic Forest in Kentucky-Tennessee and Oak-Hickory-Pine Forest further south (Braun 1950); the latter extends westward to its dryness limit in eastern Oklahoma and Texas, where the canopy is typically only about 15 m tall and only two (eastern) oaks remain as co-dominants, *Q. stellata* and *Q. marilandica*, joined in central Texas especially by *Q. texana*.

(c) **Europe**

Although summers in Europe are cooler than in the other two regions, the warm period (≥ 10°C) can be just as long. Summers in southern Europe, though, are often drier than in the nemoral region to the north, due to the higher temperatures (thermophilous) or to reduced summer precipitation (submediterranean).

In Europe (see Table 9), most of the area north of the Alps is cool-temperate, with Tmax generally below about 20°C and WI < 80 (though usually with at least 5 if not 6 warm months – the Atlantic influence). In the Rhône valley of southern France there is an abrupt jump in Tmax from 20.5°C at Lyon to 23.4°C at Avignon, with a similar increase in Tmin (2.1–5.2°C). This suggests a more typical-temperate climate to the south, as well as in northern Italy (Tmax at least 22°C); these areas all have at least 7 warm months and WI > 90, albeit with the increasingly dry Mediterranean summer. In the Iberian Peninsula, Galicia and the north coast are cool (Tmax < 20°C) but with mild winters and absolute minima that could perhaps permit broad-leaved evergreens. On the *meseta* (generally above 500 m, including northeastern Portugal), Tmax is typically 21–22°C but the colder winters still have cold-month means well above freezing; much of this area, though, is too dry for forest except in valleys or other more humid sites. In all of this western Mediterranean area, Tmax does not reach 24°C (cf. Milano, Barcelona, Madrid, Firenze) until after absolute minimum temperatures have risen well above -10°C (with means well above freezing), i.e. high enough to permit broad-leaved evergreens. As a result, there is no warm-temperate deciduous climate with the same summer temperature levels as in East Asia or eastern North America—it is already warm enough for evergreens; the same is true in Portugal, though at lower summer temperatures (cf Moreno et al. 1990).

In the mountainous, more continental Balkan area, warm-month means are typically 21–24°C but without any clear north-south break. Absolute minima are lower than in the western Mediterranean area, and winter means are as in central Europe. Here also a warm-month mean of 24°C is generally not reached (except near the coast), and some warm-month means are distinctly lower, sometimes < 20°C. This occurs already at elevations not so much higher (see values in the Appendix), as at Cluj-Napoca (410 m, in Transylvania), Ljubljana (385 m), Sofiya (586 m) and Ioannina (466 m, in NW Greece). Also here, there are thus no large areas for warm-temperate deciduous forest with summers as warm as on continental east sides. The warmer 'thermophilous' and 'submediterranean' deciduous forests of southern Europe appear to occur in thermal regimes that, elsewhere, would be considered typical temperate. Of course these conditions are still significantly warmer than in central to northern Europe and do not preclude recognition as warm-temperate deciduous woods, with thermophilous species such as *Q. pubescens*. These occur especially on the many warmer south-facing slopes.

Finally, in eastern Europe, there does seem to be a significant southward jump in summer mean temperatures between the 20.5°C at Kyyiv (Kiev) and the means of 23.0°C at Sochi and Rostov-na-Donu, and 23.7°C at Yalta on the Crimean south coast (although mean winter temperatures stay below freezing until near the coast). Although Moskva (Moscow) and Kazan both have 5 warm months, and Kazan (at the same latitude but further east) has *Q. robur* forest, both must be considered cool-temperate, as also Kyyiv. Southernmost Russia (e.g. Rostov) and Ukraina could be warm-temperate deciduous, except that they are generally too dry for forest. Zakataly (Azerbaijan) and some small areas on lower southern slopes of the Caucasus in northeastern Georgia (with no climate data) could both be seen as warm-temperate deciduous; the Georgian forests are co-dominated by *Fraxinus*, *Tilia*, *Carpinus*, *Acer*, and *Quercus iberica*, and can be very species-rich (cf Nakhutsrishvili 2012; see relevés in Box et al. 2000).

7 Conclusions and Questions

The temperature data and apparent thresholds identified in the previous section, for the three regions, show that the 'thermophilous' and 'submediterranean' deciduous forests of southern Europe occur at lower summer temperatures than in the warm-temperate deciduous forest areas of East Asia and eastern North America. This follows a general pattern of lower mid-latitude temperatures on continental west sides (e.g. Europe), due to the greater oceanic effect on the windward west sides. The lower summer temperatures in southern Europe do not necessarily mean that the European 'thermophilous' and 'submediterranean' forests cannot be called warm-temperate. Rather it means that the concept of warm-temperate deciduous forest, and perhaps of the warm-temperate climate in general, may need to be understood in relation to the general temperature levels of the particular regions. An attempt to show this discrepancy geographically is made in the last chapter of this book (Box, herein - b), by mapping potential regions based on apparent climatic limits identified in this chapter.

In East Asia and eastern North America, temperature levels are quite comparable and the concept 'warm-temperate deciduous' seems to identify, quite well, those areas with warmer summers and no continuing winter snow cover, even though winter temperatures (means or extremes) are too low for broad-leaved evergreens. These are the southernmost areas of deciduous forest, dominated by deciduous trees that also occur well into the warm-temperate evergreen areas further south, usually as the main canopy species of secondary forests. In Europe (and perhaps small areas of the northwestern USA), 'warm-temperate deciduous' also seems to identify the southernmost deciduous forests, also involving more thermophilous species, even if the actual summer temperatures are lower. Where summers are humid these forests are called thermophilous, where summer is drier they are called submediterranean. Note that this is not a vindication of Walter's climate type V, which involved west-side areas occurring much further north (marine west-coast climates, from 40° to 55° of latitude, in some cases to 60° N latitude) and with much more oceanic precipitation regimes.

Values for Kira's Warmth Index are not significantly lower in southern Europe than in East Asia or eastern North America. Furthermore, the length of the warm period is often even longer (7 months) in the thermophilous deciduous regions of southern Europe, due to the greater oceanic effect on the continental west side. Lengths of warm and wet periods were suggested already by Wang (1941) and by Lauer (1952, cf Lauer and Rafiqpoor 2002) as effective indicators of climate types and potential vegetation regions. Length of a warm-wet period (instead of a P/PET ratio) and of the warm period (instead of particular temperature thresholds) may indeed be better indicators and are being explored.

Given the above interpretation and the similar results on continental east sides, it does seem that warm-temperate deciduous forest represents a consistent and useful concept in corresponding regions on different continents, with similar climatic thresholds except for summer temperatures in Europe. Warm-temperate deciduous forests do appear to have clear climatic constraints, but these forests are also distinct in terms of their vegetation, especially the combinations of canopy dominant or co-dominant tree species involved. There may also, however, be unknown factors, involving perhaps evolutionary or more recent history, effects of topography and substrate on water balance, and aspects of microclimate not captured by a macroclimate approach. Some of these factors may be identified by the subsequent chapters in this special-session volume.