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Basics, Methods and Case Studies

Franco Pedrotti

Plant and Vegetation Mapping

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Plant and Vegetation Mapping

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Foreword

Mapping plants and vegetation has a long history in Europe, where it is known as geobotanical mapping, i.e. mapping of botany in the landscape or in relation to other geographic factors. Much of the methodology and results, however, is documented only in its original Italian, Polish, Russian or other language, and so remains largely unknown to those who read only the English, French or German scientific literature. I first became aware of this mapping tradition in 1990, at the annual meeting of the International Association for Vegetation Science in Warszawa (Poland), hosted by Janusz B. Faliński, a foremost specialist in vegetation mapping. Many detailed maps were on display, some made by quite unfamiliar methods and some a bit difficult to read but nevertheless compelling. Maps depicting vegetation dynamics or naturalness seemed especially original. Altogether, these maps demonstrated a wealth of information that was new to many of us from the 'West'.

I was reminded of this in the summer of 2010 upon first seeing the original Italian version of this book, *Cartografia Geobotanica*, by Professor Franco Pedrotti (University of Camerino). Immediately I thought that this book should be available in English. Learning to speak and write a foreign language is difficult and takes time; learning to read, on the other hand, is not difficult, especially for scientific material with its more limited and somewhat more international vocabulary. So, even though I had never studied Italian formally, it was indeed possible to translate the book by working in Camerino with the author for about 5 weeks the next summer.

This book presents mainly Italian geobotanical mapping as it developed among specialists and their students there. Most examples involve maps of Italy, and little attempt was made to include maps from wider areas because the Italian tradition provides so much already. There was also little attempt to include newer examples. In particular, the recent explosion of computer maps based on automated data sources (but often with little quality control) is not covered in great detail.

Many original terms, such as 'synphytosociological' or 'phytogeoceneoses', come across in English as very 'European' and hard to remember, even if initially understood. So, for some words, I have tried to create shorter, more analytical equivalents, using basic English words but retaining the more synthetic European constructions in parentheses. Map names in the original language are also retained, as far as possible, with English translations in parentheses. Finally, some Italian terms appear to have no English equivalents, such as *fotolimiti* (the edges or boundaries that can be discerned on an aerial photo); for these I have used familiar English words like, indeed, edge or boundary.

I hope the reader will find this book useful, understanding that it is not an attempt to be comprehensive but rather to present a mapping tradition that may otherwise not be well known. I would also like to take this opportunity to thank Franco Pedrotti for his wonderful Italian hospitality in Camerino.

Athens (Georgia) Elgene Owen Box
27 August 2011

Preface

Geobotanical maps do not represent the reality of the world but rather what we know about it.

(Janusz Bogdan Faliński)

Geobotanical research finds its syntheses in the production of cartographic documents (maps) which constitute a privileged medium of presentation of information and scientific data on plants in relation to environmental conditions. The significance of new geobotanical maps for already many years has been greatly augmented above all by the contribution that these may make to understanding and solution of environmental problems, such as protection of the flora, zonation of protected areas, management of plant resources and urban planning.

For such reasons, the Faculty of Natural Sciences and Technology of the University of Camerino instituted in 1998 the course *Geobotanical Cartography* for members of the *Scuola di Specializzazione in Gestione dell'Ambiente Naturale e delle Aree Protette* (School of Management of the Natural Environment and Protected Areas) and for students in the Natural and Biological Sciences as a general degree course.

In this book, born of the necessity to provide students a textbook for geobotanical cartography, we try to present the fundamental concepts in this field, which are otherwise sparse in truly scientific publications which often have limited circulation and are difficult to find. This has theoretical as well as practical value, and tries to give the students both an instructional aid for preparation for their exams and theses, and a reference text. Given the high degree of specialization in the material treated, this text is filled with many bibliographic references from various authors, not only to give the reader the greatest possibility for research from original sources but also as a cultural basis.

The book is concerned principally with geobotanical mapping but also contains a chapter dedicated to environmental mapping, because of the contribution that this has received from the former and because of its own current trends and contributions.

In drafting the text, I have tried to improve and expand on what I already wrote about geobotanical mapping in earlier contributions. The text is dedicated predominantly to botanical aspects of cartography and only in part to those techniques (photogrammetry, use of satellite data, etc.) for which numerous, more specialized manuals already exist.

Beginning in 1962, in the Institute of Botany of the University of Camerino (from 1986 the Department of Botany and Ecology), I have had the possibility to collect data and produce geobotanical maps of various kinds, with a group of students and collaborators whom I would like to mention here: Ettore Orsomando, Edoardo Biondi (now at the University of Ancona), Roberto Venanzoni (now University of Perugia), Dan Gafta (now University of Cluj-Napoca, Romania), Krunica Hruska, Andrea Catorci, Paolo Minghetti, Aurelio Manzi, Renato Gerdol (now University of Ferrara), Fabio Taffetani (now University of Ancona), Claudio Chemini (now at the Centro di Ecologia Alpina in Viotte del Monte Bondone of Trento) and Rainer Buchwald (now Universität Vechta, Germany) for vegetation mapping; Carmela Cortini, Michele Aleffi, Sandro Ballelli and Fabio Conti for floristic mapping; and Roberto Canullo and Giandiego Campetella for mapping of populations. To these must be added researchers from other institutes, in particular Francesco Maria Raimondo (Palermo) and Filippo Piccoli (Ferrara). More recently, there has been a group of students of the School of Management of the Natural Environment and Protected Areas of Camerino that is dedicated, under my guidance, to various aspects of cartography: Luciana Carotenuto (Pavia), Anna Maria Castellaneta (Martina Franca), Wilcka Fanesi (Osimo), Renzo Feliziani (Acquasanta Terme), Simone Galassi (Macerata), Jessica Mazzarelli (Foce di Montemonaco), Stefania Menini (Livorno), Bruno Petriccione (Roma), Donatella Rosi (Visso), Sergio Ruggieri (Vieste), Roberta Tacchi (San Severino Marche) and Rosella Vallozzi (Ascoli Piceno).

Finally, I am particularly happy to acknowledge some botanists and ecologists with whom I have been able to study various aspects of geobotanical and environmental mapping, in the laboratory and in the field: the late Janusz Bogdan Faliński (Białowieza and Warsaw), Maximo Liberman Cruz (La Paz, Bolivia), Marcello Martinelli (São Paulo, Brazil), Paul Ozenda (Grenoble), Udo Bohn (Bad Godesberg) and Vasile Cristea (Cluj-Napoca). Janusz Bogdan Faliński, who is the author of the three-volume manual *Kartografia Geobotaniczna* (1990–1991), and I have together described the vegetation of the Gargano (promontory) of Adriatic Italy, of the Białowieza forest in Poland and of Pikhtovka in Siberia. To Dan Gafta (Cluj-Napoca), I am indebted for advice on the content of the book and for critical reading of the text.

I thank Marco Mogetta (Camerino) for producing the layout and Massimo Maccari (Camerino) for preparing printed illustrations and for correcting the proofs.

Particular thanks go to Augusto Persico and to the SELCA of Firenze (Florence), which has a grand tradition in cartographic publication, for supplying specific contributions.

The English edition of my book *Cartografia Geobotanica* was made possible thanks to Prof. Elgene O. Box of the University of Georgia, Athens, USA, who as a friend made himself available for the task of translating the book text from Italian into English.

The structure of the book and the division of the themes into 14 chapters was left the same as in the original, but many chapters were expanded with new information and bibliographic references. Some illustrations were also modified.

The discussions with Prof. Box during the translation work (which was done in Camerino during July 2011) were very useful for improving the original text. Together we have travelled to various parts of the world for geobotanic purposes, beginning with the international phytosociological excursion to Argentina in 1983 and followed by field excursions to Japan, USA, South Africa, Mexico and various countries of Europe, including Italy, France, Poland and Romania. Also, the symposia of the *International Association of Vegetation Science* and of the *Association Amicale Francophone de Phytosociologie* (organized at Rinteln by Rheinold Tüxen and at Bailleul by Jean-Marie Géhu and then in other cities) have provided opportunities to meet and discuss with many botanists interested in vegetation mapping, including Kazue Fujiwara (Yokohama), Frédéric Bioret (Brest), Guillaume Decocq (Amiens), Richard Pott (Hannover), Rüdiger Wittig (Frankfurt am Mein), Xavier Loidi (Bilbao), Laco Mucina (Perth) and others (in addition to the many mentioned already in the introduction to the Italian version of the book).

I am very grateful to Prof. Box for his challenging translation work and thank him very deeply. I thank also Massimo Maccari (Camerino), who adapted the figures for the English edition and prepared the new figures.

Camerino
21 September 2011 Franco Pedrotti

Contents

Geobotanical Mapping and Its Levels of Study

1

Definition of Geobotanical Mapping

Geobotany is a broad science that deals with the study of species and of vegetation communities in relation to the environment; it includes other, perhaps more familiar sciences, such as plant geography, plant ecology, and chorology, and phytosociology (plant sociology).

Geobotanical cartography is a field of *thematic cartography* that deals with the interpretation and representation, in the form of maps, of those spatial and temporal phenomena that pertain to flora, vegetation, vegetated landscapes, vegetation zones, and phytogeographical units.

The production of a geobotanical map represents the last stage in a cognitive process that begins with observations in the field and continues with the collection of sample data, interpretation of the phenomena observed, and their appropriate cartographic representation; geobotanical cartography is closely tied to the concepts and scope of *geobotany* in general.

It was Rübel (1912a) who first used the term 'geobotanical cartography', but only for the mapping of vegetation. Nevertheless, its meaning was amplified later to include the mapping of all phytogeographic, phytocoenotic and phytosociological aspects, as emphasized by Faliński (1990–1991, 1999). A *phytocoenosis* is a concrete vegetation stand in the field, as opposed to a *community*, which is theoretical; and *phytosociology* is the analytical classification of plant communities based on full-floristic vegetation samples called *relevés*. From this it is evident that the field of research called *geobotanical cartography* is in fact broader than that of *vegetation mapping*.

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A Bit of History

Geobotanical mapping began relatively recently, about the middle of the 1800s, but developed rapidly during the 1900s. Its beginning was preceded by a lengthy formative period, during which there were various floristic, phytogeographical and vegetation investigations, with the development of elaborate theories, which in turn led to the production of true cartographic documents. Some international congresses pointed out goals attained by geobotanical mapping and objectives to pursue. The most recent such congresses were held in Stolzenau in 1959 (Tüxen 1963), in Tolosa in 1961 (Gaussen 1961a), in St. Petersburg in 1975 (Sochava and Isachenko 1976), in Klagenfurt in 1979 (Ozenda 1980–1982), in Grenoble in 1980 (Ozenda 1981), in Warsaw in 1990 (Faliński 1991), again in Grenoble in 1996 (Michalet and Pautou 1998) and in České Budějovice in 1997 (Bredenkamp et al. 1998). Specialists from all over the world participated in these congresses, which contributed ideas in various areas of cartography.

Journals dedicated to cartography were also published, such as the *Bulletin du Service de la Carte Phytogéographique* edited by Louis Emberger (Montpellier) beginning in 1956 (now discontinued); the *Documents pour la Carte de la végétation des Alpes,* then *Documents de Cartographie Écologique* (1963–1987) edited by Paul Ozenda (Grenoble); *Geobotaniceskoe Kartografirovanie (Geobotanical Mapping)* (from 1963) edited by V.B. Sochava and E.M. Lavrenko (Saint Petersburg); and the *Supplementum Cartographiae Geobotanicae* (from 1988) edited by Janusz Bogdan Faliński (Białowieza-Warsaw).

During all this time the production of vegetation maps increased and improved in both form and content, culminating in 2000 in the publication of the *Map of the Natural Vegetation of Europe* directed by Udo Bohn (Bad Godesberg) and involving coordinating work by Robert Neuhäusl (Prague-Průhonice), Wladyslaw Matuszkiewicz (Warsaw), Paul Ozenda (Grenoble), Tatiana Yurkovskaya (Saint Petersburg) and others (Bohn et al. 2000a,b, 2003).

Numerous specialized publications on vegetation mapping, illustrating both theoretical and practical aspects, were also produced (e.g. Sochava 1954, 1962, 1979; Küchler 1967; Ozenda 1986; Küchler and Zonneveld 1988; Faliński 1990–1991; Pirola and Vianello 1992; Alexander and Millington 2000), as well as geobotanical publications that contain chapters on cartography (Braun-Blanquet 1928, 1951, 1964; Tomaselli 1956a; Ozenda 1964, 1982; Borza and Boşcaiu 1965; Puscaru-Soroceanu and Popova-Cucu 1966; Ivan and Doniţă 1975; Ivan 1979; Dierschke 1994; Cristea et al. 2004; and others). A quite readable and less specialized summary of vegetation mapping, including its earlier history, was provided by de Laubenfels (1975).

Levels of Synthesis in Geobotanical Mapping

The themes and other subjects that can be represented on geobotanical maps are quite diverse. These correspond to the level of geobotanical study and can be listed as follow (see also Fig. 1.1):

I. *Level of individual plants* (species): the mapping of plant populations in great detail, as may be used in studies of competition, facilitation, vegetative regeneration, dynamic processes, etc., which manifest themselves in small areas; the scale of such maps varies according to the dimensions of the individual plants.

II. *Level of populations* (species): distributions of populations of plant species in a particular territory.

III. *Level of synusiae*: mapping of the synusiae present in a definite phytocoenosis. A synusia (see Chap. 3) is a group of structurally and functionally similar plant species in a vegetation stand. According to Gams (1918), synusiae can be distinguished at a first order (populations of a single species in a phytocoenosis), at a second order (populations of more species all belonging to the same life form), and at a third order (populations of diverse species that differ structurally by each occupying a particular microhabitat). In fact, in accepted current usage, the concept of a synusia of order I coincides with that of a population and that of a synusia of order III coincides with that of a microphytocoenosis (for example, epixylous assemblages on fallen trunks or epilithic assemblages on large rocks in the understorey). Normally the objective of mapping at this level is a synusia of order III, which has a wider connotation, especially in ecology, than that of order I or II. The term synusia, on the other hand, has been used by many authors with sometimes quite different meanings, as in the cases of Barkman (1973), Guinochet (1973), Vigo (1998) and others. Referring to synusiae, some authors have proposed a new concept, that of coeno-association, which will be examined briefly in Chap. 6 (section on Maps of Coeno-Associations) (Gillet 1986, 1988; Gillet et al. 1991; Gillet and Gallandat 1996).

IV. *Level of phytocoenosis*: mapping of vegetation types of higher floristic homoteneity[1] found in specific stable conditions; corresponds to classic phytosociological mapping at the level of associations or subassociations (Braun-Blanquet 1964) and to mapping based on classifications that refer to other definite vegetation units from other schools, such as phytogeocoenoses (Sukachev and Zonn 1961).

[1] Homoteneity is a synthetic concept based on all the relevés collected for diverse phytocoenoses belonging to the same type of community (van der Maarel and Westhoff 1973). An association has high homoteneity if the expression $(S_{IV} + S_V)/(S_{II} + S_{III}) > 1$, which is to say that the proportion of dominant species (constancy $> 60\%$) is greater than in the neutral model of a random distribution of species in the plant community (S_i = number of species that re-enter in classes of constancy i).

V. *Level of ecotopes* (*teselas*): the mapping of vegetation series, or synphytosociological units, based on the concepts of sigmeta or vegetation series or sigma-associations according to Rivas-Martínez (1985) and Géhu (1991a).

VI. *Level of catenas* (vegetated landscapes): at the scale being used, this coincides with geo-synphytosociological or catenal mapping, which is based on the concept of geoseries or geosigmeta or catenas of vegetation series (Géhu 1991a).

VII. *Level of lower phytogeographical units*: land areas that are distinct in terms of their distributions of species, genera and families and in particular their endemics; one can distinguish also lower and higher phytogeographical units (see level VIII); the lower phytogeographical units were called districts, sectors and provinces (or dominions) by Rivas-Martínez (1985) and, respectively, meso-chorocomplexes, macro-chorocomplexes and mega-chorocomplexes by Theurillat (1992, 1994).

VIII. *Level of higher phytogeographical units* (regions and kingdoms) *and biomes*: this level can involve very different kinds of maps due to the two possible bases for subdivision of the vegetation cover of the world, namely according to the flora or the vegetation type. Maps of floristic subdivisions (phytogeographic maps) are based on qualitative and quantitative characteristics of the flora, as opposed to maps of vegetation zonation, which are based on qualitative and quantitative characteristics of the vegetation formations. Maps that represent phytogeographic regions and kingdoms use, as the fundamental criterion, the floristic uniqueness of a particular territory, including its endemics. Maps of vegetation zones are based on the physiognomy of the vegetation formation and on the climate in which it developed.

Levels I and II are for mapping populations, and level II also for mapping chorological (or floristical) areas; level III is for mapping synusiae; levels IV and

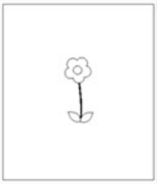
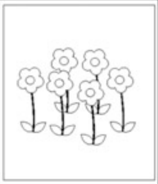
Level	Schematic	Abstract unit (theoretical model)	Map type	
I. Individual plant		Species	Phytoecological	Floristic cartography
II. Population		Species	Populations and chorology	

Fig. 1.1 (continued)

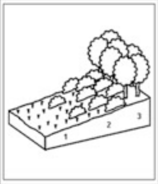
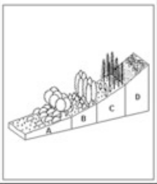
Level	Schematic	Abstract unit (theoretical model)	Map type	
III. Synusia		"Association"	Synusial	Vegetation cartography
IV. Vegetation stand (phytocoenosis)		Plant association	Phytosociological	
V. "Tesela"		Sigmetum (series)	Synphytosociological or Dynamic-phytosociological or Integrated-phytosociological	
VI. Catena (vegetated landscape)		Geosigmetum (geoseries)	Geo-synphytosociological	
VII. Lower plant-geographic units		District, Sector, Province	Regional-phytogeographical	Plant-geographical cartography
VIIIa. Higher plant-geographic units		Region, Kingdom	Plant-geographical	
VIIIb. Biomes		Zone and belt vegetation	Global-phytoclimatical	

Fig. 1.1 Levels of synthesis in geobotanical mapping

V are for mapping vegetation distributions; level VI is for plant or vegetation landscapes (geo-synphytosociological mapping); and levels VII and VIII are for phytogeographical mapping and the mapping of vegetation formations.

Types of Geobotanical Maps

Based on the above, it is possible to distinguish the following types of maps, with the levels of synthesis (above) shown in parentheses:

Population maps (levels I and II)
Chorological maps (level II)
Synusial maps (level III)
Vegetation maps (phytosociological maps of actual or potential vegetation, etc.) (levels IV and V)
Landscape maps (geo-synphytosociological maps) (level VI)
Phytogeographical maps at lower level (level VII)
Phytogeographical maps at higher level and maps of vegetation distribution (vegetation formations) (level VIII).

These cartographies are very different from each other, by map content or by techniques of representation. Nevertheless they all integrate knowledge of complex biological phenomena, as are found in the plant world.

To these map types already listed can be added the phytoecological maps, which may treat species, including individuals and populations (autoecology), or vegetation (synecology), according to the particular goals.

Finally, one must also mention the maps of plant biodiversity.

2 Mapping Populations

A plant population is the set of the individuals (organisms, phytoindividuals) of the same species that live in a given place at a given moment and interact with each other. A mapping of individuals coincides in part with that of populations, but it is still preferable to keep the two types (phytoindividuals and populations) distinct because they have different meanings and purposes, and because the methodologies used may be different.

Maps at this level, at fine (large) scale, are today a useful basis for conservation biology, since threatened species have greater probability of surviving due to the *rescue effect* involving migration between neighboring populations. On the other hand, maps at broader (smaller) scale become chorological, in that they may contain entire populations or, more generically, the absolute range of a species.

Maps of Individual Plants

The purpose of maps of individual plants is to represent their distributions in localized areas. The mapping is done at a fine scale, recording also the composition in terms of organisms (units) of diverse types and functions (Falińska 1984). Beyond just the spatial representation of complex individuals, including genotypes identified by molecular methods (Figs. 2.1 and 2.2), this kind of the mapping permits monitoring all individuals in permanent areas, generally small but adequate, from 1/4 m^2 to a few tens of m^2 (Fig. 2.3). Naturally the mapping of herbaceous species is always more complex than that of woody species, as can be seen in Fig. 2.4, which shows a plot of 50 × 50 m inside which all individuals of the herbaceous species present have been mapped.

Repeated mapping over time permits gathering information on the manner and rate of growth of the individuals, hence of the population that they compose (Fig. 2.5), and on the duration and disappearance of the individuals (Fig. 2.6), etc.

Use of sophisticated geopositioning systems (from theodolites to GPS) does not always result in the adequate required level of detail, as opposed to simpler and more immediate topographic positioning by means of corner coordinates, which

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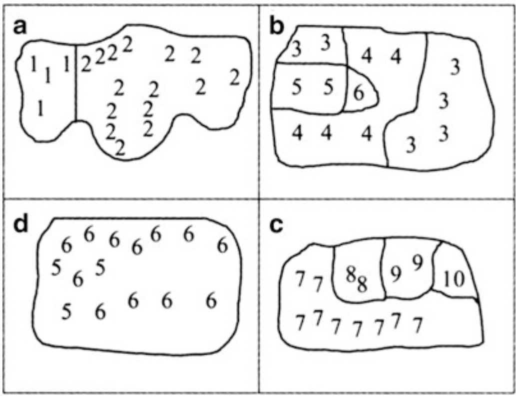

Fig. 2.1 Distribution of four populations genotypes of *Festuca rubra* (**a**, **b**, **c**, **d**) identified by electrophoresis; the *numbers* shows different genotypes (From Falińska 1998)

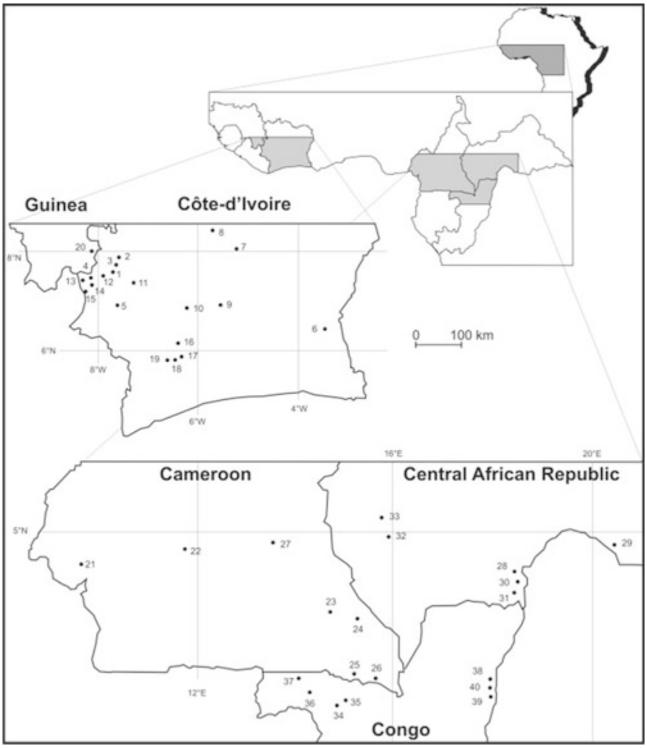

Fig. 2.2 Geographic and genetic origins of the wild *Coffea canephora* genotypes in West and Central Africa; the *numbers* corresponds to different genotypes names and origin (From Gomez et al. 2009)

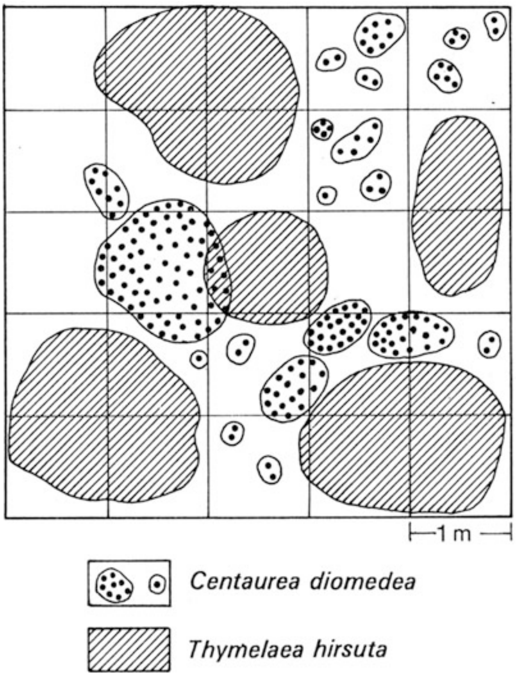

Fig. 2.3 Spatial distribution of *Centaurea diomedea* individuals between those of *Thymelaea hirsuta*, Tremiti Islands, southern Italy (From Falińska 1999)

permit finding the mapped unit also at less phenologically optimum moments and with minimal impact. In these cases, the geographic coordinates of individuals are measured directly in the field, as for two populations of *Polylepis tarapacana* from the Nevado Sajama (Andes of Bolivia) in areas of about 4,000 m^2, with the following distinct functional age classes: seedling, young individual, fertile adult, sterile adult and dead individual (Fig. 2.7).

Naturally these considerations depend on the dimensions of the organisms: woody species require more space and benefit from more modern techniques for topographic positioning, such as photogrammetry (Fig. 2.8) or remote sensing (Fig. 2.9).

Generally, maps of the distribution of individual trees are made for rare species, as in the case of the Nebrodi fir (*Abies nebrodensis*), a species which exists in nature only as 30 individuals and as such has been mapped repeatedly, three times over the past 30 years (Fig. 2.10) (Morandini 1969; Morandini et al. 1994; Virgilio et al. 2000); and the case of the *bagolaro* (*Celtis tournefortii*), with a range limited to a few sites on the southwest slope of Mt. Etna (Fig. 2.11). Mapping of this type has also been done for the century-old individuals of larch pine (*Pinus laricio*), noted as the "giants of Sila" in the forest Bosco Fallistro (Avolio and Ciancio 1985), and for the *Quercus pubescens* trees of the zone Abbadia di Fiastra in the Marche (region) of Adriatic Italy, in which pollution damage suffered by the trees is indicated distinctly in four classes: no damage, plus light, moderate and severe damage (Fig. 2.12).

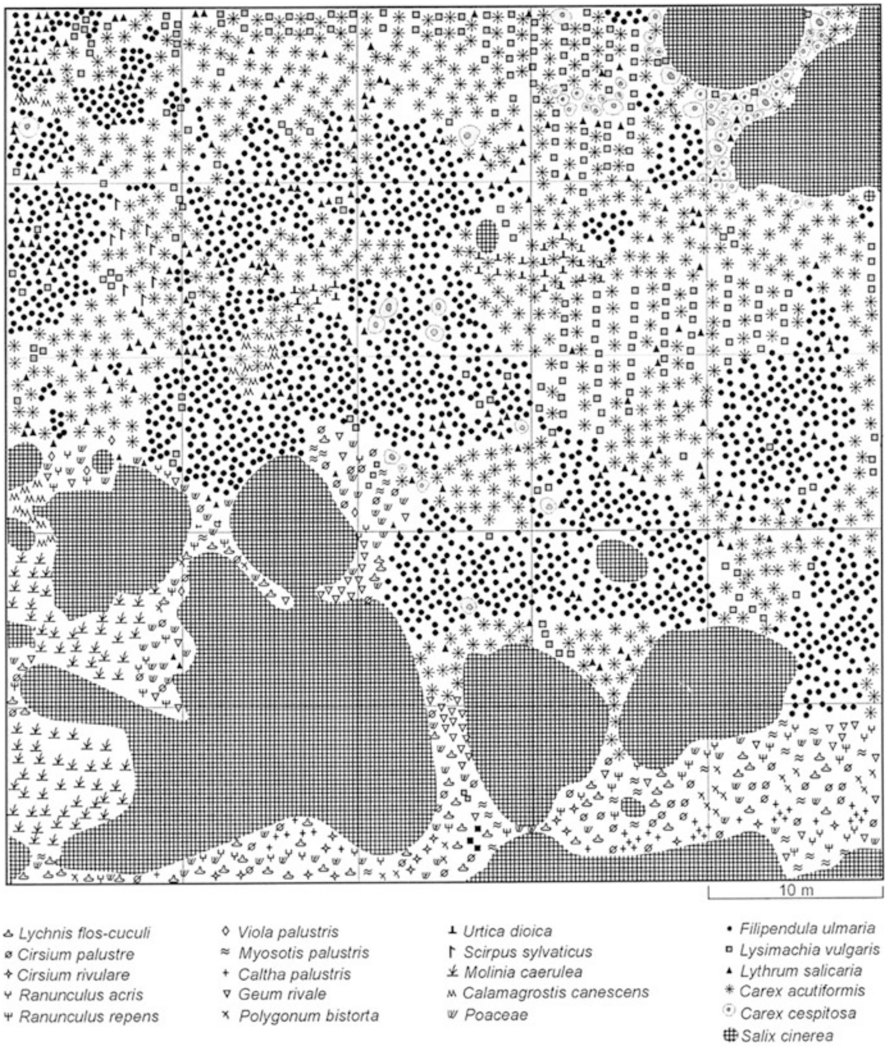

Fig. 2.4 Spatial distribution of perennial herbaceous species in abandoned meadow in the Remski wetland, Narewka Valley, Białowieza (Poland) after 25 years, partially invaded by *Salix cinerea* (From Falińska 2003)

Trees are also mapped as a function of their ecology. Kondō and Sakai (2011) surveyed and mapped some tree species in relation to microtopography in a mountain area of central Japan. The species there occur mainly in particular geomorphological situations, such as *Salix cardiophylla* on debris cones; *Tsuga diversifolia*, *Abies mariesii* and *Abies veitchii* on mountain slopes and terraces; and *Alnus matsumurae* on valley and lower slopes (Fig. 2.13).

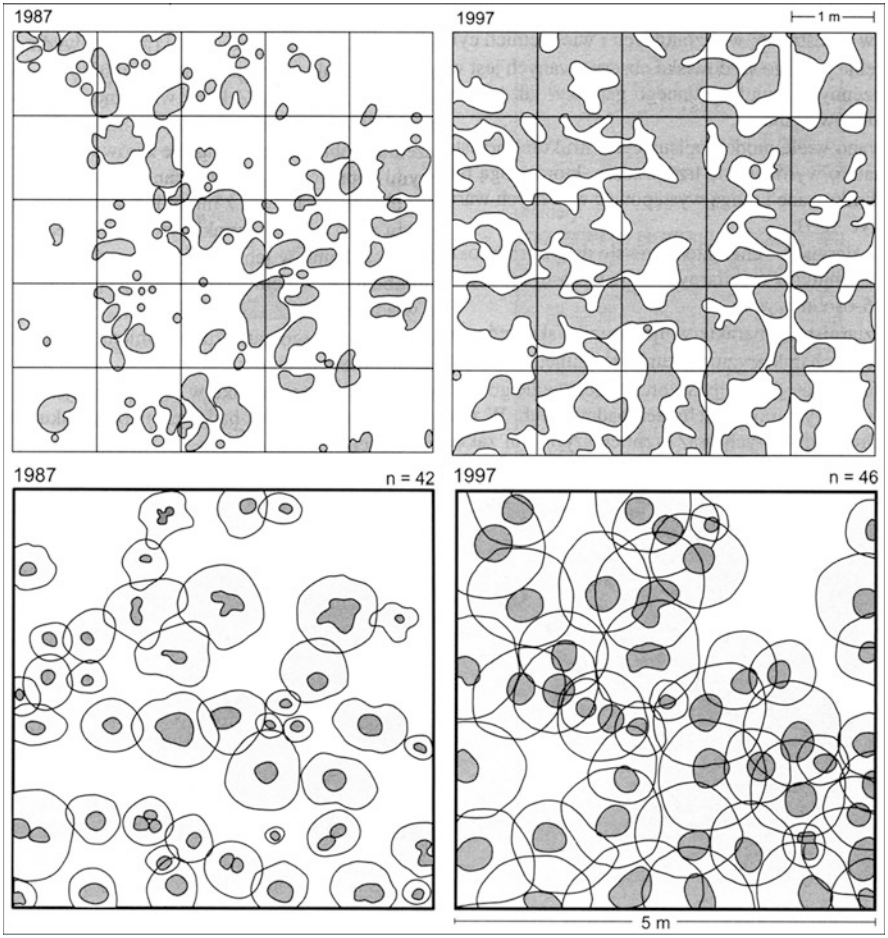

Fig. 2.5 Spatial dynamic of a population of *Filipendula ulmaria* and another of *Carex caespitosa*, from 1987 to 1997 (From Falińska 2002)

Individual trees have also been mapped for the remains of two forests left standing under water when the two lakes in Trentino were created by a landslide around 1000BC. At the end of the Lago di Molveno lake, which was drained completely for construction of a hydroelectric impoundment, 142 individuals belonging to 7 species have been found and mapped, among them *Abies alba*, *Taxus baccata* and *Fagus sylvatica* (Marchesoni 1954). At the Lago di Tenno lake, 74 individuals belonging to 7 species were found and mapped, including especially *Fagus sylvatica* (Fig. 2.14). This mapping was done by a diver who marked the trunks found by means of cables tied to floats. Using a theodolite along the shoreline, it was possible to map the positions of the individual floats, each of which corresponded to a tree trunk on the

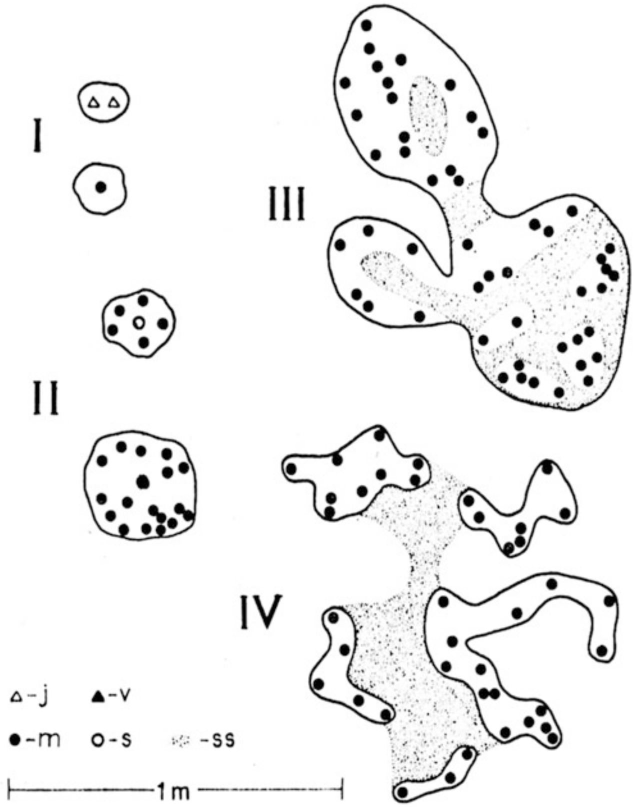

Fig. 2.6 Development and shape variation of *Filipendula ulmaria* polycormon. Development phases: *I* – beginning, *II* – juvenile; *III* – mature; *IV* – senescent (over 10 years); *j* – young, *v* – virginale (physiologically ready for reproduction; but still without differentiated reproductive organs), *m* – fertile; *s* – old, *ss* – dead parts of the underground organs (From Falińska 1984)

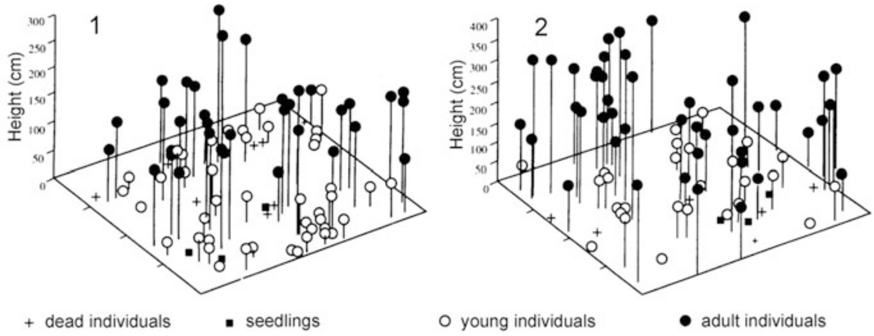

Fig. 2.7 Spatial distribution of two populations of *Polylepis tarapacana*, Nevado Sajama, Bolivia, number 1 at 4,720 m and number 2 at 4,370 m; dimensions and age were surveyed for each individual (From Liberman Cruz et al. 1997)

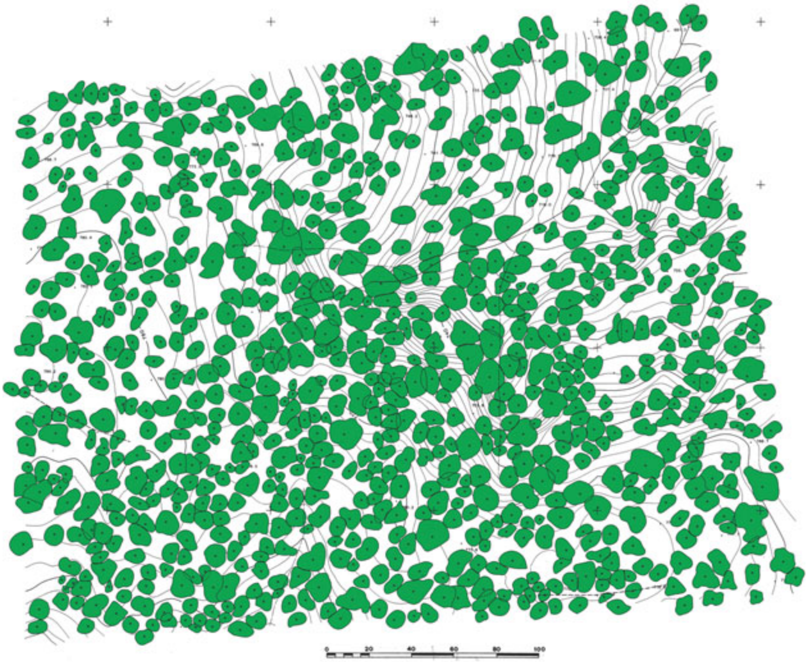

Fig. 2.8 Distribution of *Fagus sylvatica* trees in the canopy of forest in the Riserva Pavari, Foresta Umbra, Mt. Gargano, Apulia region of Adriatic; southern Italy; the distribution was obtained by photorestitution

lake bottom. With such research it is possible to understand the composition of the forest at the time the lakes were formed.

Maps of Populations

Cartographic representation of one population may involve:

– One species in a phytocoenosis (coenopopulation or coenotic population, i.e. all individuals of the same species in a phytocoenosis), at the location of a given ecosystem; in this case it is possible to show the dynamic and spatial relations of subpopulations and ecotonal or synusial populations (Fig. 2.15); or
– One species in a territory (administrative, geomorphological, landscape, etc.) in which different coenotic populations are distinguishable; in this case it is possible to show the functional relations within the metapopulations, i.e. a set of populations connected by a flow of individuals but separated by environmental heterogeneity and various dynamic processes (including phenology).

Mapping the dynamics of these populations permits expression of the relations among ecological and dynamic processes in populations, interpretable as spatial process patterns that can occur simultaneously or sequentially in a single "dynamic

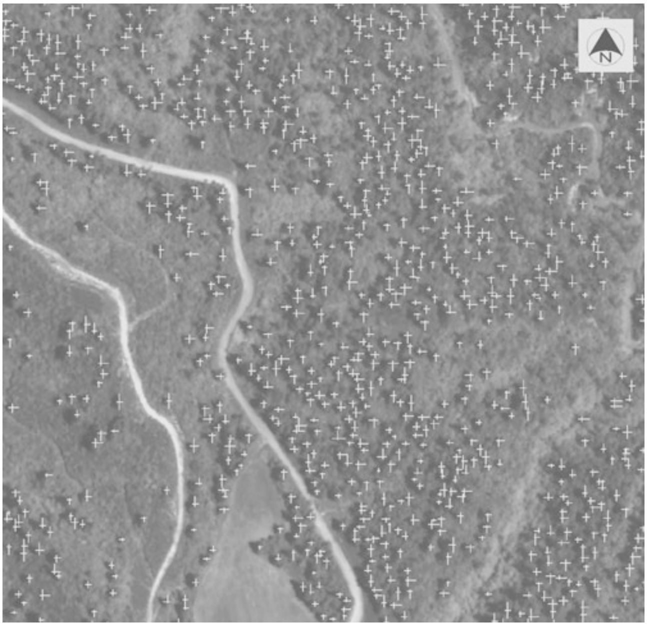

Fig. 2.9 IKONOS image Carterra PAN – MS (1 and 4 m resolution) from 22 June, 2000, on the Kassandra peninsula, Chalkidiki, Greece. The image show the number of *Pinus halepensis* trees and the density of tree biomass, as represented by *crosses* of different sizes (*Software developed by Advanced Computer Systems A.C.S. S.p.A., Rome*)

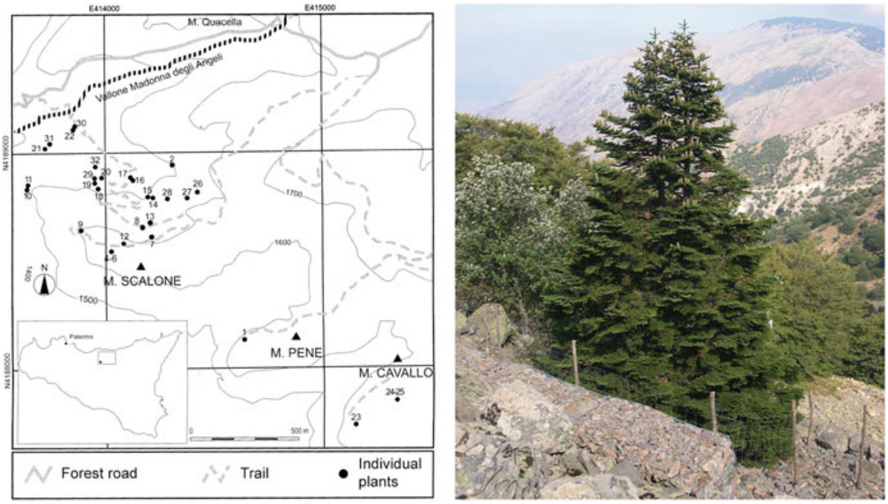

Fig. 2.10 On the *left*, the distribution of individual *Abies nebrodensis*; trees, numbered from 1 to 32, Mt. Scalone, Sicily; on the *right*, the tree no. 27 (From Virgilio et al. 2000; photo Rosario Schicchi)

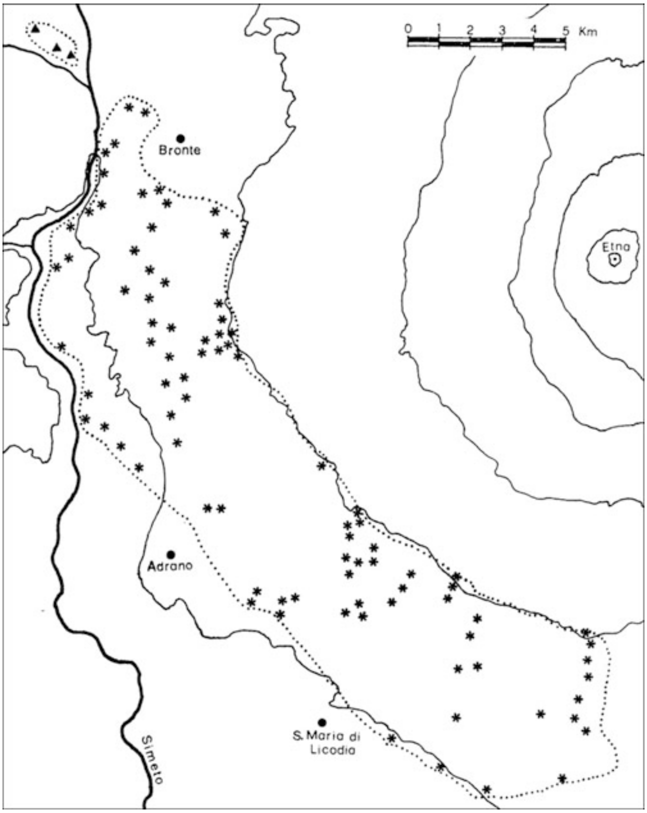

Fig. 2.11 Distribution of *Celtis tournefortii* on Mt. Etna, Sicily (From Poli et al. 1974)

landscape". The expansion of a species on a territory can be described as a complex balance among distinct populations in various dynamic states (pioneers, expanding, regressing, etc.) (Canullo 1991b, 1993a, b), as can be seen in the case of *Anemone nemorosa* at Białowieza (Fig. 2.16) and of *Cytisus sessilifolius* at Torricchio (Fig. 2.17). The variations in the populations can be observed and mapped also in relation to the various successional stages of the communities in which they occur, for example during the secondary succession of a marsh and progressive formation of a shrubby stand of *Salix cinerea* (Fig. 2.18) or of *Alnus glutinosa* (Fig. 2.19), or of *Cyclamen hederifolium* in the beechwood of Mt. Gargano (Fig. 2.20). In the wetland area of Reski (Białowieza forest), Falińska (2003) followed variations in populations in the association Cirsietum rivularis from 1980 to 1995, producing four maps, one every 5 years. The wetland was invaded progressively by shrub species, in particular *Salix cinerea*, which replaced the pre-existing populations of herbaceous species completely over the course of the 15 years (Fig. 2.18).