GEODESY AND CARTOGRAPHY
ISSN 2029-6991 / eISSN 2029-7009
2017 VOLUME 43(2): 73–81
https://doi.org/10.3846/20296991.2017.1330769

UDK 528.944

MAPS OF NATIVE RANGES OF TROPICAL AND SUBTROPICAL PLANTS CREATED BY GIS

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Received 3 April 2017; accepted 10 May 2017

Abstract. This article presents various methods employed for construction of maps of native ranges of plants using geographical information system (GIS). The maps were originally created for a set of publications on important tropical and subtropical plants species kept in the collections of Flora Olomouc Exhibition Grounds, JSC., Czech Republic. Two different approaches were applied using outlined and chorochromatic methods. The former was used for construction of maps depicting approximate ranges, i.e., ranges which cannot be constructed exactly due to the objective lack of biogeographical data (e.g. early domesticated crops, which no longer occur in the wild). The latter approach was used for construction of maps showing known ranges, i.e., ranges that can be constructed more or less exactly because there is no considerable lack of biogeographical data. The maps of known ranges could be further divided according to the total area of the depicted range, its shape or location. The paper also presents plans of the greenhouses and the exhibition complex at Flora Olomouc Exhibition Grounds, using a different type of thematic maps useful for large-scale mapping of living collections.

Keywords: thematic map, GIS, cartography, biogeography, native range.

Introduction

In 2013, three books were published about the greenhouses at Flora Olomouc Exhibition Grounds, JSC. (Czech Republic). The books include a selection of the most interesting and most precious plants grown in the individual greenhouses (Dančák *et al.* 2013a, 2013b, 2013c). The complex of greenhouses is made up of a palm, a tropical and a subtropical greenhouse, housing predominantly plant species from the tropical and subtropical regions of the world. The books are written in Czech and are addressed to professional botanists and botany students as well as to the general public. The books were written by a team of botanists in cooperation with cartographers. Each species is given one page in the book. A textual description of each species is divided into three parts: distribution and ecology; morphology description; and interesting facts about the species. The text is accompanied by photographs of the plant, along with a map of its native range. An example of this page layout is shown in Figure 1.

The maps of native ranges of plant species were drawn up for the purpose of the above-mentioned books by cartographers as original map drawings, which for the most part have not been published elsewhere. The maps are the result of the collective work of cartographers and botanists. With the publication of the three books, a unique collection of 115 maps was created, delineating native ranges of the presented plant species. All the maps have the same format. Along with these maps, the three publications also offer plans of all the individual greenhouses with marked locations of the plants, as well as a comprehensible orientation plan of the whole complex.

Since the paper uses the term *native range of the species*, it is necessary to define it. Each plant species

evolved in a specific place on Earth, where it in most cases also currently occurs. However, a large number of species later also expanded into neighbouring or more distant areas. If they did so spontaneously, through natural processes without human contribution, these areas are called *native ranges* (Webb 1985; Smith 1986; Pyšek *et al.* 2004). A large number of species was also disseminated by people, whether intentionally or unintentionally. Most often they were crops or ornamental species, namely those species that are used by people for some purpose and are mostly also deliberately grown by them. Apart from crops, such was also the case of species sustained by usually unintentional human activity, such as weeds and ruderal species. Some of these species, whether disseminated intentionally or unintentionally, may then find suitable conditions in the new environment and may subsequently spread further without human contribution. It may be easy to determine the native range of a given species, although in many cases, such as the first crops, it is difficult if not impossible (Zohary *et al.* 2012). Localization of the native range may be interesting also because it is sometimes limited to a small area or because a given species does not occur in the native area any longer. This article offers an overview of methods of cartographic delineation of native ranges of plants using GIS (Geographical Information System) software.


4116–4117

SOLANDRA MAXIMA

(Sessé & Moc.) P.S. Green

Solandra největší

Syn.: *Datura maxima* Sessé & Moc., *Solandra hartwegii* C.F. Ball, *Solandra nitida* Zuccagni

Čeleď: *Solanaceae* Juss. – lilkovité

PŮVOD, EKOLOGIE

Druh pochází ze Střední Ameriky, od Mexika až do Panamy. Druhotně je rozšířen v mnoha subtropických oblastech světa. Je to tropická popínavá rostlina světlých až polostinných stanovišť.

POPIS

Vytrvalá popínavá dřevnatá liána s bohatě větveným kmínkem dorůstá délky až 12 m, ale obvykle jen 3–6 m. Listy má kožovitě tuhé, eliptické až obvejčité, dlouhé až 25 cm a široké až 10 cm. Květy jsou nápadně velké (kalich až 8 cm dlouhý, koruna 15–25 cm dlouhá a 8–15 cm široká), nálevkovitého tvaru, žluté barvy s purpurovou kresbou uvnitř. Květy příjemně voní, lákají opylovače (netopýry). Plodem je až 7 cm velká bobule s přetrvávajícím kalichem.

ZAJÍMAVOSTI

Rod *Solandra*, který zahrnuje 10 druhů, byl pojmenován po žákovi C. Linného, švédském botanikovi D. C. Solanderovi (1733–1782). V našich klimatických podmínkách se tento druh pěstuje jako sbírková rostlina v teplých sklenících. Pro obrovské květy bývá v tropech a teplejších subtropech pěstována v zahradách a parcích. Množí se semeny i vegetativně vyzrálými osními řízky.

38 / Zajímavé rostliny subtropického skleníku

Fig. 1. A page dealings with the Central American species of *Solandra maxima* (Dančák *et al.* 2013c)

1. Selected cartographic methods and map content

A simple topographic background was selected for all the maps. It is largely made of a given continent or its smaller part, where state borders are marked with the colour black. The colour white is used to render the territory of the state. Water areas (seas and oceans) are shown in blue. Individual scales differ, as the goal for each map was to show the whole continent or at least its part in order to make it clear which continent the map displays. A method utilizing area symbols was chosen to provide a topographic background and to highlight the main theme. Area symbols have two parameters – fill and outline (Voženílek, Kaňok 2011). The colour red was selected as fill for the main theme of the map, that is, the particular native range. In some cases, there is only a red outline of the range with no colour fill. The colour red was chosen due to its distinctive character in order to highlight the main theme.

Maps of native ranges are examples of chorochromatic maps. The chorochromatic map shows only nominal data for displayed areas with the use of different colours (Kraak, Ormeling 2003). Three main ways of displaying ranges are used in plant chorology: a) a point method b) a contour method c) an outline method (Lomolino 2006; Morrone 2012). The most often used method for displaying whole ranges is the outline one, which constructs a range by connecting peripheral localities of the occurrence of a given taxon. This is the method we have chosen. It is especially suitable in those cases where finding all the known specific localities of the species occurrence would be disproportionally difficult, not corresponding with the purpose of the map or utterly impossible. The disadvantage of this method is that it does not reflect the inner structure of the range and thus actually represents, from the cartographic point of view, a form of generalization of map content. The method is therefore mostly used for small scale maps, where a degree of generalization is necessary regardless the quality of the input data. Visualization methods for uncertainty data is mentioned in the article by Brus *et al.* (2013).

The maps do not include any textual description, as they are easy to read. A textual description of each species starts with a textual description of the species distribution (Fig. 1). For instance, for the species of *Codiaeum variegatum* (variegated croton), the following text is presented: "Croton is native to the western Pacific Ocean islands and northern Australia, from where it expands westwards as far as the islands Celebes and Java" (Dančák *et al.* 2013a). This text is illustrated by the map in Figure 2.

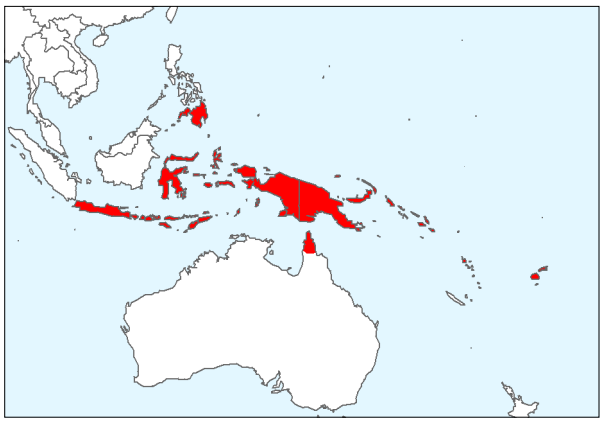

Fig. 2. Map of the native range of *Codiaeum variegatum*

2. Methods of displaying native ranges

All the three published books offer several typical methods of displaying native ranges, which can be divided into characteristic groups. These methods are described in more detail further in the text.

2.1. Approximate native range

A representation of an approximate range was used in those cases when the actual area of the native range is not known with certainty. In the case of a number of early domesticated crops, botanists only assume, or rather infer based on direct or indirect evidence, where their native range used to be. At any rate, the native range of these plants is not accurately known, and it is in effect currently no longer possible to determine it with greater accuracy. In this case a method using area symbols (chorochromatic map) was chosen as a cartographic method of representation, wherein a red schematic delineation represents the approximate native range. The native range is only delineated in red colour, with no interior red fill. Since in such cases neither the border of the range nor its shape is known, the shape of the range was predominantly delineated simply by a circle or an ellipse (Fig. 3).

There are several such cases in the set of maps in the published books. These cases deal mostly with early domesticated crops which do not occur in the wild any longer. *Carica papaya* (papaya) can be seen as such an example. This plant probably comes from the central part of Central America (Fig. 4). The precise place of origin of the species is not known due to a long history of its cultivation, during which the plant was spread by humans into other areas. Nowadays it is solely a cultivated plant and does not occur in the wild.

The native range for *Punica granatum* (pomegranate) is delineated in a similar way (Fig. 3). Its origin is described as follows: "*Punica granatum* is native to the area of the Middle East, probably Iran. Already in ancient times, it gradually expanded into the area of the Near East and Northern Africa, Central Asia and further into India and China" (Dančák *et al.* 2013c).

2.2. Known native range

A red area symbol was always used in the process of delineating a known native range. With regard to a great variety in size and shape of native ranges, it was necessary to deal with a problem of displaying territories of different size or different composition. Methods of displaying a known native range can be divided into several groups.

2.2.1. Native range only on a small island or an archipelago of small islands

In case the native range is limited only to a specific small island or an archipelago of small islands, it is delineated by a larger red circle or ellipse (Fig. 4), which highlights the distribution of the species on the islands.

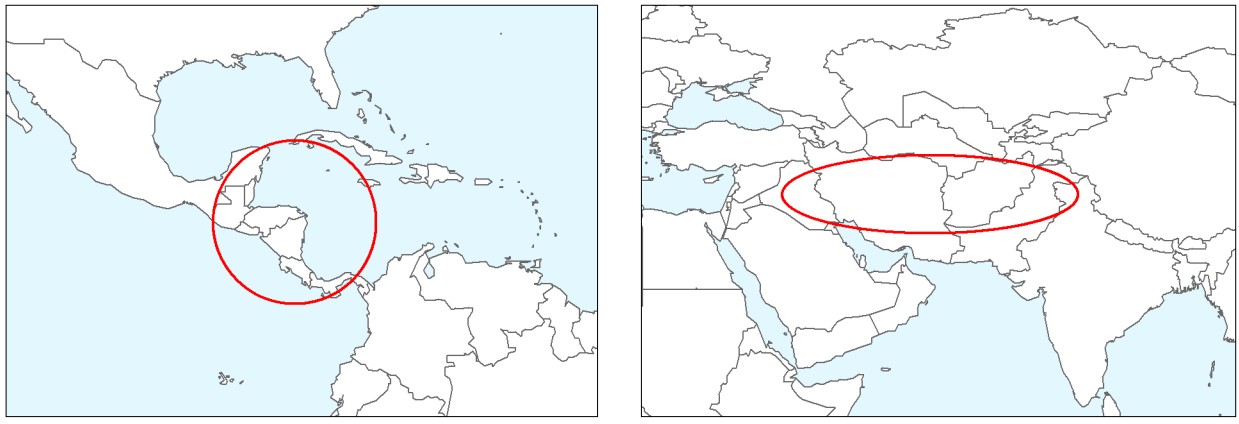

Fig. 3. Examples of the approximate native range of *Carica papaya* (left) and *Punica granatun* (right)

Fig. 4. Native range on an archipelago: *Dracaena draco*

An alternative option was using a red colour fill for the territory of an island or archipelago. This method was impossible to use for small islands, because a red colour fill was almost illegible in a small-scale map. A full colour fill was used for bigger islands, as it can be seen for instance in Figure 5 (right), which shows the native range of *Cyperus alternifolius* (umbrella papyrus) on the island of Madagascar.

2.2.2. Native range on mainland and on big islands – continuous area

In a number of cases, species are distributed in a specific delineated continuous area on mainland. Either it is an area along a coastline or an inland area. In this case the area was delineated by an area symbol with a red fill. The border of the range had to observe very carefully the data supplied by the botanist. In a number of cases a plant species is dependent on a specific sea level, watercourses or biotope. The illustration in Figure 5 (left) is for the plant *Pachystachys lutea* (lollipop plant). This species originates from Peru, and its native range slightly expands into the Brazilian state Acre (Dančák *et al.* 2013b). The same cartographic method was also chosen for big islands (Fig. 5, right).

2.2.3. Native range on mainland – discontinuous area

Of some interest are native ranges that are situated on mainland but are not continuous. Individual separate parts of a given native range, or range fragments, are separated by gaps, or so-called disjunctions, where a given species does not occur. A disjunctive native range can be observed in case of *Dioon edule* (chestnut dioon), which originates from two separate areas along the eastern coastline of Mexico (Dančák *et al.* 2013a). It grows in tropical half-deciduous forests and oak forests on dry places with shallow soil. It is evident that its native range is closely dependent on a specific biotope. A red area symbol with a red fill was used again to delineate the range (Fig. 6).

Another example is the species *Monstera lechleriana* (Fig. 6, right), which grows in northern parts of South America, from where it continuously expands into Panama and Costa Rica. A distinctly separated range fragment also lies in southern Mexico. In this case, it is a taxonomically unresolved species, most likely comprising actually two very similar species, one of which grows in Mexico, while the other occupies the rest of the displayed range. However, the current state of knowledge does not allow botanists to unambiguously assess whether both displayed fragment ranges or only one of them can be seen as pertaining to the given species.

2.2.4. Native ranges involving both mainland and islands

Range delineation is perhaps most complicated when the range is vast and encompasses parts of mainland and larger areas of bigger or smaller islands. In this

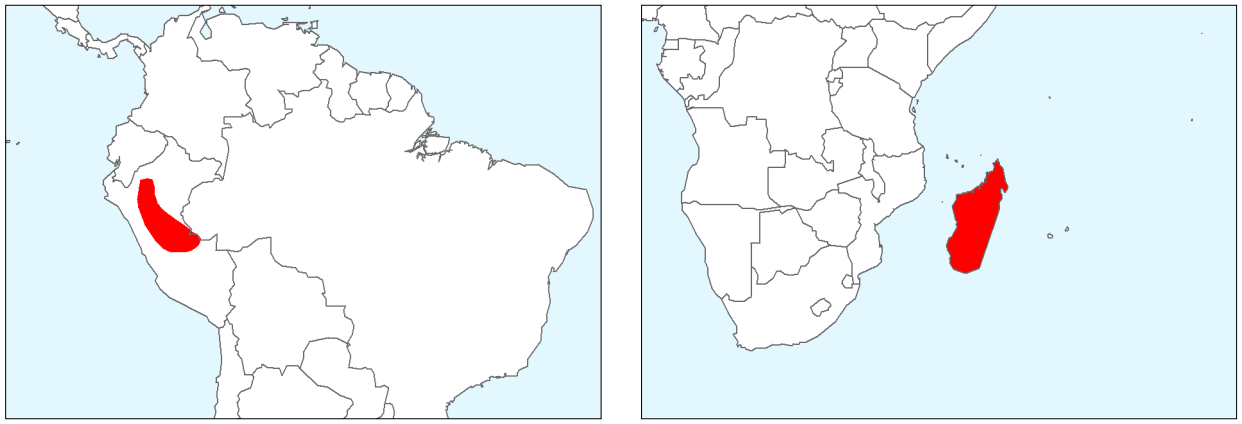

Fig. 5. Native range on mainland: *Pachystachys lutea* (left) and *Cyperus alternifolius* (right)

case, a red fill was used for a larger vast territory on mainland and for bigger islands. Smaller islands as well as the whole range were circumscribed with a red delineating line, which continuously extends into the range on the mainland. The map in Figure 7 shows the native range of *Pandanus tectorius* (thatch screwpine) (Dančák *et al.* 2013a). The second illustration shows the native range of *Asplenium nidus* (bird's-nest fern) (Dančák *et al.* 2013b).

2.2.5. Specific area – the Mediterranean

The Mediterranean, especially its coastline regions, is the native range for a number of plants kept in the subtropical greenhouse. Maps of the Mediterranean species distributions display very diverse disjunctive ranges, which were difficult to draw accurately. Two examples of these maps are shown in Figure 8. One of the examples is *Olea europea* (olive), a species originating from Northern Africa, Southern Europe and

Fig. 6. Discontinuous mainland ranges. Native range of *Dioon edule* made of two separated fragment ranges (left). Taxonomic complex comprising possibly of two taxa: *Monstera lechleriana* (right)

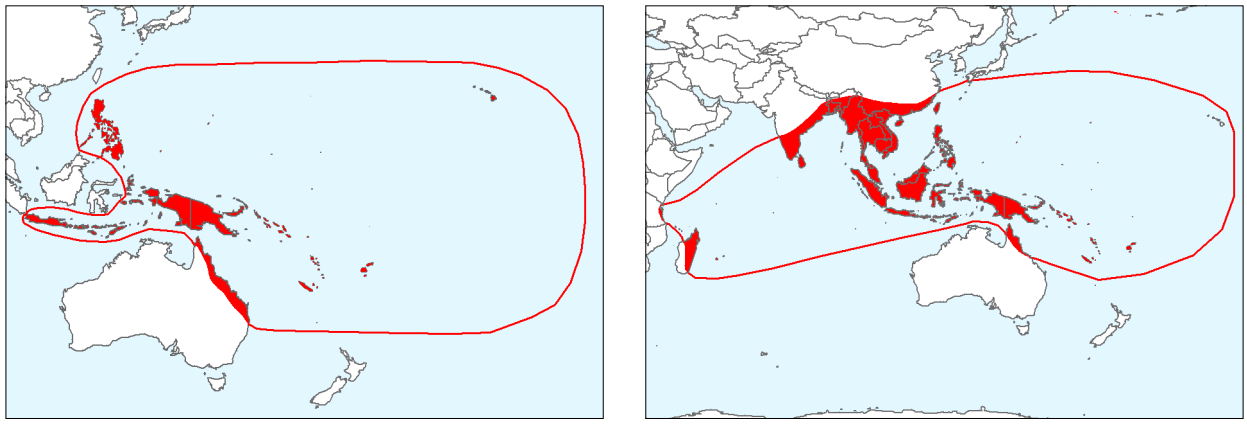

Fig. 7. Native range of *Pandanus tectorius* (left) and *Asplenium nidus* (right), involving both mainland and islands

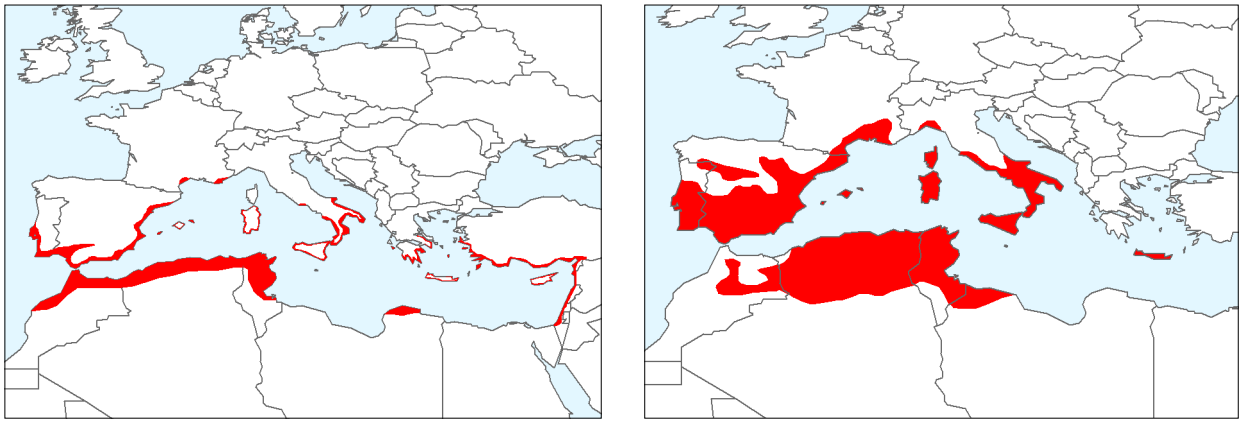

Fig. 8. Mediterranean ranges for *Olea europea* (left) and *Rosmarinus officinalis* (right)

Eastern Mediterranean. The olive tree is one of the oldest crops in the world. It was probably Phoenicians who introduced it outside its native range and today it is the most widely grown woody plant in the Mediterranean. Nowadays the olive tree is prevalent not only in the whole of the Mediterranean and the Black Sea region but it is also grown in Southern and Southeast Africa, the Indian Peninsula, Japan, Australia, California, Florida, Jamaica, Peru, Chile and Argentina (Dančák *et al.* 2013c).

The second map in Figure 8 (on the right) shows the native range of *Rosmarinus officinalis* (rosemary) (Dančák *et al.* 2013c). Rosemary is native to the western Mediterranean as well as to Southern Europe and Northern Africa. From the given examples, it is evident that the native range of both species is discontinuous, comprising a number of Mediterranean islands. It is also evident that in some cases the distribution is limited to a narrow strip of coastal mainland.

3. Map preparation technology

GIS gives a new possibilities in the cartographic production process (Pődör 2015). A GIS software ArcGIS developed by ESRI was used for the creation of the maps. This program was chosen because it has useful and advanced cartographic functions (Dobesova 2013b). The source data for the continents were taken from the dataset "Data and Maps for ArcGIS", which are available free of charge along with ArcGIS. These datasets include basic topographic data for the whole world.

Data is provided in Esri's compressed, direct-read, high-performance Smart Data Compression (SDC) format. The datasets follow the Federal Geographic Data Committee (FGDC) standard and contain ISO 19115-compliant metadata (Esri 2014).

Fig. 9. Map of the native range of *Howea belmoreana* on Lord Howe Island

Individual native ranges were created in SHP vector format. For the purpose of fitting the maps onto the page, the original size of all them was set at 4×5 cm. The map scales therefore vary.

All the thematic maps were elaborated based on preliminary maps prepared by the third author of the article. Distribution maps of some species were already available in specialist botanical publications; these could be basically copied after minor editing (e.g. correction of mistakes or generalization or completion of data). From the point of generalization, the simplification method was used. The goal of simplification is to retain as much of the geometry of the feature as possible, while eliminating the maximum number of coordinates (Slocum *et al.* 2004).

In other cases, map preparation was also very simple, especially in the case of endemic species in well defined territories such as islands. One such example is *Howea belmoreana* (kentia palm), which naturally occurs only on Lord Howe Island in the Tasmanian Sea (part of the Pacific Ocean) between Australia and New Zealand (Fig. 9). The delineation of its range is simply made by a red circle.

Preparation of other maps was nevertheless difficult, involving compilation of several textual or map sources. Many of the presented maps are thus original, based on the adaptation of particular original sources, and they have never been published before.

4. Plans of the greenhouses and the exhibition complex

Among other thematic plans prepared for the individual books there were detailed orientation plans of the greenhouses with the drawn locations of the plants. Each book encloses a comprehensible orientation plan of the collection greenhouses and the adjacent botanical garden of Palacky University in Olomouc (Fig. 11). University botany classes are held in both complexes.

Figure 10 shows the plan of the subtropical greenhouse. Each plant is given an identification number. This number is given to the plant in the plan of the greenhouse as well. The list of plants is listed under the plan. Thanks to this plan it is easy to look up a given plant in the greenhouse. A dark green colour marks the locations of important plants, all of which are described in the book about the subtropical greenhouse. These are all of the 33 species displayed in the book. A light green colour marks the locations of all the other plants growing in the greenhouse. Altogether the plan

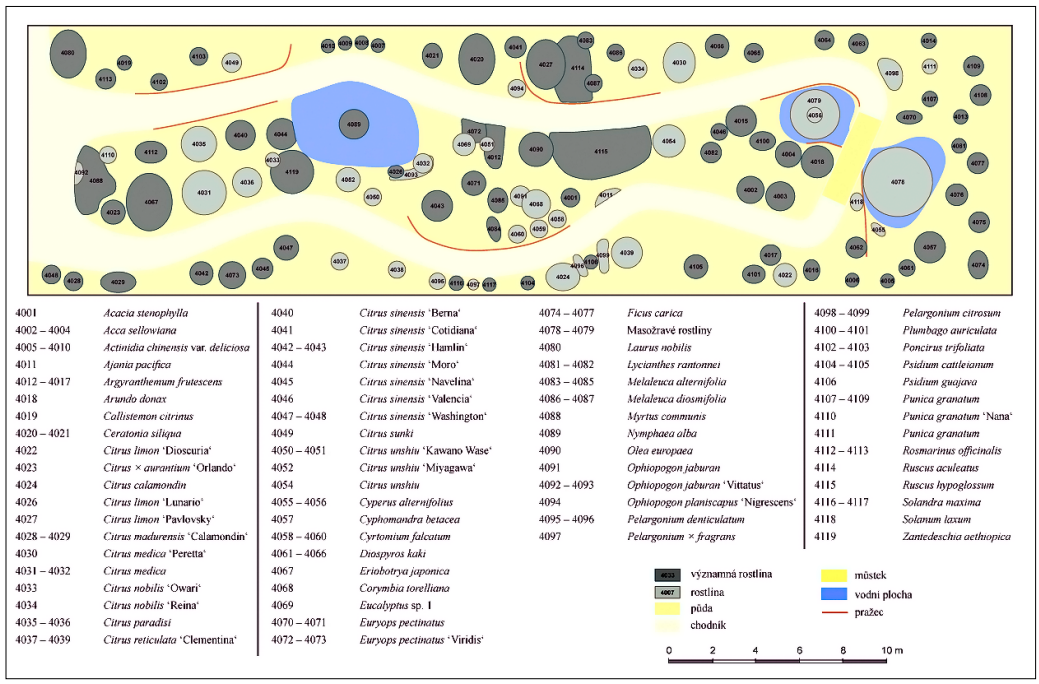

Fig. 10. Plan of the subtropical greenhouse (Dančák *et al.* 2013c)

includes 110 plants. Primarily, this plan was used for the information billboard placed in the area of the entrance to the greenhouse. The original scale is 1:40, but in the publication the plan has obviously been made smaller.

The other two plans, for the palm and the tropical greenhouse, were also prepared in a similar way. In the books, they were printed as folded two- or three-page sheets, which can be spread out when the book is opened. All the maps are also available in the interactive form at www.botangis.upol.cz.

A comprehensible plan of the whole complex schematically displays outdoor premises of the botanical garden and the premises of the greenhouses. It is designed as a comprehensible orientation source for students and visitors. In the printed version the plan has the A4 format. Furthermore, the plan was included in all the above-mentioned publications about the greenhouses. It displays the overall location of the greenhouses and the botanical garden; a basic description of the compounds is also included. The cartographic principle of associativity was observed during the selection of colours (Dobesova *et al.* 2013c). Green areas represent exhibition areas of plants, whereas the colour blue was used to indicate inside and outside water areas. Pavements are identically marked by the colour yellow in both complexes. The plan involves two visitor trails. The first trail leads through the botanic garden, while the other trail goes through the greenhouses, which are open to the public all the year round. Along the trails, there are signs indicating respective entrances and the recommended tour route, which is shown by a red line. The colour red was

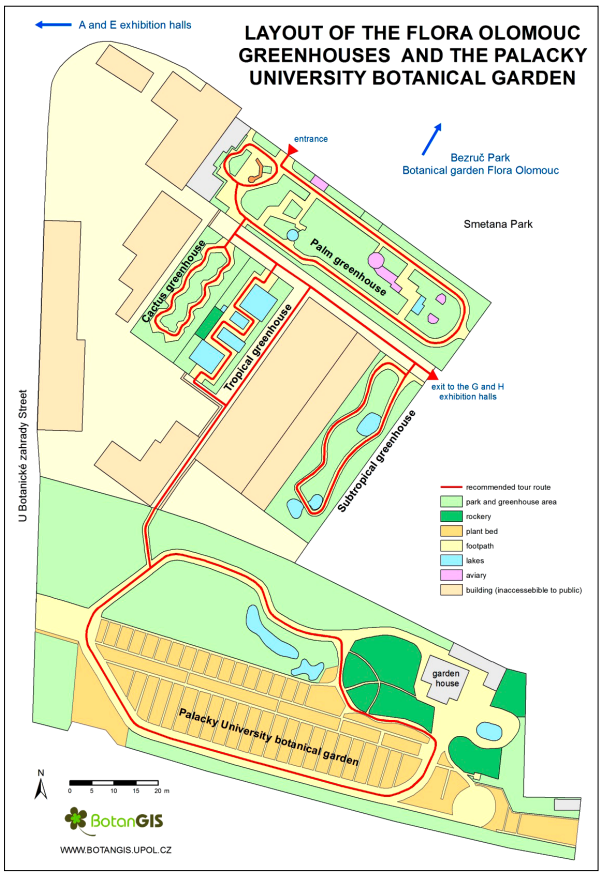

Fig. 11. The plan of the Flora Olomouc greenhouses and the Palacky University botanical garden

chosen in order to distinctly convey thematic information, namely the course of the tour's trail (Dobesova 2012; Dobesova *et al.* 2013a).

Conclusions

This article is the result of fruitful cooperation between botanists and cartographers, which gave rise to an extensive set of maps of native ranges of selected species of plants. These maps are included in three books about the species grown in the greenhouses at Flora Olomouc Exhibition Grounds, JSC. The advantage of the maps is that the information about the location of native ranges, their expanse and localization on the continents is conveyed faster. An expert botanist has thus yet another way of imparting information. Information provided by a map is faster than a lengthy textual description. In the books, however, a textual description with a precise localization comprises a description of each plant species. The map therefore completes the text and the text completes the map. In this case, the map and the text offer complementary information.

The distribution maps of the plants are divided into six different types. They include maps with a known native range and with an approximate one. Further, there are outlined cartographic methods of mapping, where the distribution is limited to big or small islands, mainland or the combination of the two possibilities (mainland and islands). Creating maps of plant distribution in the Mediterranean was a specific case. In the Mediterranean the plant distribution covers vast territories, especially its diverse strips of coastal mainland, which made map creation quite labour-intensive.

The second cartographic output comprises a set of plans of the individual greenhouses and a comprehensible orientation plan. These plans are also used both in the individual books and on the billboards in the greenhouses.

The presented outputs of the cooperation of the botanist and the cartographer are an example of cartographers supplementing botanical study materials with map creation. The enclosed maps and plans add to the quality of the botanic information.

Acknowledgments

The authors gratefully acknowledge the support by the Operational Program Education for Competitiveness – European Social Fund (project CZ.1.07/2.3.00/20.0170 of the Ministry of Education, Youth and Sports of the Czech Republic).

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