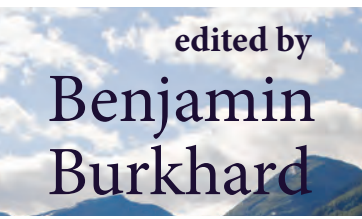




MAPPING



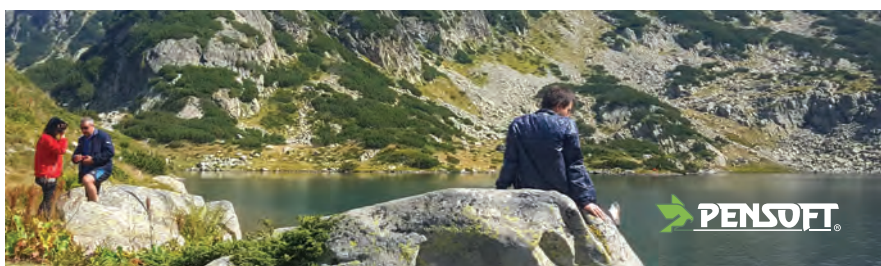
ECOSYSTEM SERVICES



edited by
**Benjamin
Burkhard**



& **Joachim
Maes**



MAPPING ECOSYSTEM SERVICES

Edited by: Benjamin Burkhard, Joachim Maes



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3.2. Mapping techniques

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Introduction

Mapping is about the graphical representation of spatio-temporal phenomena. Illustrating our complex environment by symbols and graphics requires important decisions: Does the chosen map type properly reflect the Ecosystem Service(s) (ES) to be portrayed? Are more intuitive design choices available to visualise and explain a particular dataset? What happens if the map type does not fit the data? This chapter aims to investigate popular map types like dot maps, choropleth maps, proportional symbol maps, isarithmic maps and marker maps. We relate those types to inherent spatial and statistical characteristics of certain ES phenomena and give advice on advantages and possible pitfalls related to their usage.

Every ES map, whether paper or digital, is a graphical representation of ES in their geographic context. In most cases, such maps are built to facilitate understanding of ES in their spatial (Chapter 5.2) and/or temporal (Chapter 5.3) dimension. What kind of ES data should be presented to whom (e.g. general public, scientific community, ES-practitioners) greatly determine the mapping process: a process of abstraction from geographic reality to the final map. Scientific cartography developed an extensive body of theory and derived practical guidelines to accomplish this process. A major goal thereof is the provision of maps that can be intuitively read and correctly understood and used by the intended end user (Chapter 6.4).

Matching data and map type

Data are the result of measurements (Chapter 4.1), modelling (Chapter 4.4) or other quantifications (Chapter 4) of geographic phenomena. Air temperature data, for example, is typically gathered by taking measurements at several point locations. Data on tree diameters might look similar, since it uses the same geometry (points) and is measured on a metric level. However, the represented phenomenon (trees) is entirely different in nature, since trees only exist at discrete locations in space, while atmospheric conditions are continuously distributed and can be measured everywhere.

Different data models can be used to store, analyse and present spatial data, for example in Geographic Information Systems (GIS): Vector data models represent discrete or continuous spatial phenomena by using points, lines and polygons. Vector data have high accuracy for displaying features with distinct boundaries; vector map data files usually use less memory capacity.

Raster data represent the world in a regular grid of cells (pixels). Raster models are often used for continuously varying phenomena or they are the result of remote sensing.

It is possible to convert vector to raster data and vice versa. However, based on the different data model concepts, such conversions normally lead to loss of information and/or data accuracy.

When defining maps as graphic representations with the aim of facilitating the understanding of spatial phenomena, mapping techniques that properly reflect their main spatial characteristics should be chosen. But what does properly reflect mean? According to the congruence principle from cognitive design, the structure and content of visualisations should correspond to the desired structure and content of mental representations. The basic mapping concept of scaling geographic space is appropriate in this respect, since distances and directions between entities are adequately represented by the scaled distances and directions of their corresponding map symbols (except when mapping on continental scale and projection distortion is apparent). Thus it facilitates the development of mental models on the respective spatial configuration. However, it makes a difference whether a spatially continuous geographic phenomenon like the air is represented as a set of discrete dots or by alternative graphic means corresponding better to its spatial continuity.

Spatial phenomena can be categorised based on spatial continuity and spatial (in)dependence. For each possible combination, Figure 1 suggests a specific mapping technique, as discussed in the following section.

	Spatially discrete (Phenomenon only occurs at distinct, separate locations)	Spatially continuous (Phenomenon is defined everywhere)
Abrupt changes (Measured properties change abruptly over space)	Example: Number of people working in National Parks (continental scale) Consider using a Proportional Symbol map	Example: Strenght of environmental protection laws Consider using a Choropleth map
Smooth changes (Measured properties change smoothly over space)	Example: Number of salamander sightings in different regions of a national park Consider using a Dot (density) map	Example: Change of mean annual temperature from 1950-2015 Consider using a Isarithmic map

Figure 1. Models of geographic phenomena and suggested symbolisation methods. Simplified after MacEachren (1992).

While such a scheme can assist in selecting an appropriate thematic mapping technique for quantitative data, there are further corresponding considerations:

- What is the intended usage of the ES map (Chapter 5.4)? Does it merely act as an interface with the ES relevant entities, should it provide an overview on general spatial patterns or is it intended to allow for local comparisons?
- Is the data related to individual locations or is it aggregated to enumeration units?
- Is the data standardised (e.g. rates) or not (raw counts)?

The following section describes important thematic mapping techniques while addressing such considerations.

Mapping techniques

Common thematic mapping techniques include dot (density) maps, marker maps, choropleth maps, proportional symbol maps and isarithmic maps.

Dot (density) maps

In their simplest form of one-to-one feature correspondence, dot maps (also known as dot distribution maps) follow a very easy concept: at each location of the mapped entity, there is a corresponding small symbol in the map. Although this one-dot-per-feature approach is increasingly popular even in small scales and with very large numbers of features¹, dots quickly coalesce to a shading of variable intensity, which might be un-

¹ <http://demographics.coopercenter.org/DotMap/>

favourable for certain applications. In that case, a one-to-many approach is favourable, where each dot represents a fixed number of entities (e.g.: 1 dot = 100 people). The choice of the number of entities per dot is related to the chosen dot size, the scale and the density of feature locations. As a rule of thumb, points should start to coalesce in the map areas of maximum density.

Dot maps are especially suited to focus on the distribution patterns of entities or on differences in local densities. When using the dot density approach for polygonal aggregated data (e.g. number of people per district), the according number of points is placed within each polygon. To determine the position of each point within its polygon, several options apply:

- Random point distribution is straightforward and often used, although it might be misleading in cases with a very uneven distribution (e.g. randomly distributing points representing the population of Egypt on the country area).
- Adjust the point positioning within a polygon by using information on densities in neighbouring polygons.
- Use of ancillary information (e.g. settlement information from remote sensing data) for more precise point allocation.

Dot density maps which are based on aggregated data require absolute counts as a basis (e.g. number of persons per county). In addition, the use of an area-preserving map projection (see Chapter 3.1) is essential, since the density impression results from the number of dots per area unit on the map.

Heat maps are frequently seen derivatives of dot maps. Instead of showing the actual dots, they use areal colouring to represent their density. Dense areas get more reddish

colours (therefore “heat”) while areas with sparse data are normally coloured in blue. Although heat maps are quite popular, it is somewhat difficult to derive actual point feature numbers for a certain area.

Marker maps

Marker maps are a special form of dot maps that emerged with the advent of web mapping applications such as Google maps. Lying on top of a topographic base map, every marker or “pushpin” symbolises a feature of interest in its geographic location. With each marker being hyperlinked, the user can obtain additional object information or trigger certain actions, like booking a hotel room. The map itself acts foremost as an interface to data which is structured by its spatial location.

Paper maps showing the location of entities often use different symbols for different object types referenced in a legend. Thus the selection of the currently relevant object is performed visually by the user. Contrary to this, a web map allows the user to query the objects of interest within a database first and then show the query result in the map. Consequently, no further graphical differentiation of markers is necessary (but still possible).

Point markers are used to depict any type of feature geometry in the map, be it points, lines or areas. The main reason refraining from clickable areal symbols is explained by interaction challenges with other objects lying within the same area. Marker maps are often used to encode qualitative information. They mainly inform the user about individual locations and the spatial distribution pattern of the entities of interest. To prevent markers from coalescing in small scales, different mechanisms for grouping and/or selection can be applied.

Choropleth maps

Choropleth maps are preferably used to map data collected for areal units, such as states, census areas or eco-regions. Their main purpose is to provide an overview of quantitative spatial patterns across the area of interest. To construct a choropleth map, the data for each unit is aggregated into one value. According to their values, the areal units are typically grouped into classes and a colour is assigned to each class. This requires the use of meaningful colour-schemes² (Chapter 3.3), representing the sequential or diverging nature of the mapped phenomenon.

Although choropleth maps are very common, several pitfalls are inherently associated with them:

Variation within units is ignored, although the mapped phenomenon might vary considerably within (especially larger) units.

The boundaries between units often do not align with discontinuities in the mapped phenomenon. Especially the historically defined boundaries of administrative units often poorly align with spatial discontinuities of current social or natural processes (Chapter 5.2). Both problems, namely the variation within units and the definition of spatial boundaries apply for many ES and belong to the so called Modifiable Areal Unit Problem (MAUP; see Chapter 6.1).

Choropleth maps are only suitable for mapping standardised (“normalised”) data like rates (yield per ha per year) or densities (persons per km²). Mapping absolute values (e.g. counts of persons per unit) is wrong since size differences of individual units will greatly affect the result: large units will tend to have higher values, small units lower ones. Even for experienced map users, it is impossible to mentally disentangle the

resulting relationship between unit-size and colour for correcting the wrong impression of spatial distributions (compare Figure 2). However, in most cases, standardised values can be easily derived from raw counts.

In summary, choropleth maps are a good choice to demonstrate standardised data aggregated to areal units, especially if there is little variation within units and the boundaries of the units are meaningful for the mapped phenomenon.

Proportional symbol maps

Based on our assumption that ‘larger’ means ‘more’, proportional symbol maps use variation in symbol size to depict quantities. While the size of point symbols can be used to denote quantitative attributes of point features (e.g. spring symbols scaled to water outputs), scaled point symbols are also used to represent data aggregated to areas, as discussed for choropleth maps. Contrary to the latter, not only is the colour of the areal units modified based on an attribute, but a point symbol is positioned within each area and the size of this symbol is scaled according to the desired attribute. Since comparing sizes is much easier than comparing shades, proportional symbol maps are especially effective for comparison tasks. According to the scheme in Figure 1, proportional symbol maps best connote spatially discrete entities with spatially unrelated attributes. In contrast to choropleth maps, they are capable of handling absolute data like raw object counts within differently sized areas. This is possible due to the fact that larger symbols can be related to larger areas quite intuitively (Figure 3).

In their basic form, the area of a symbol is scaled proportionally to the magnitude of

² <http://colorbrewer2.org>

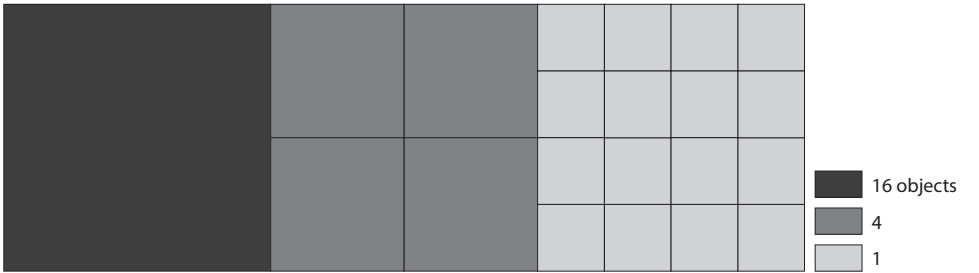
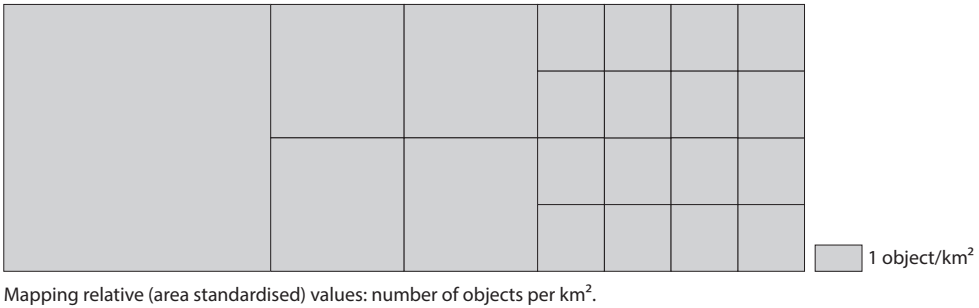
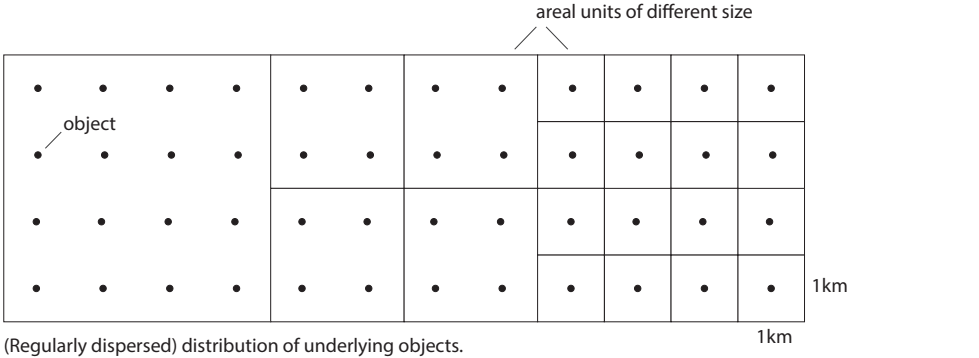


Figure 2. Only standardised data (rates etc.) should be mapped with choropleth maps. Inspired by Slocum (2009).

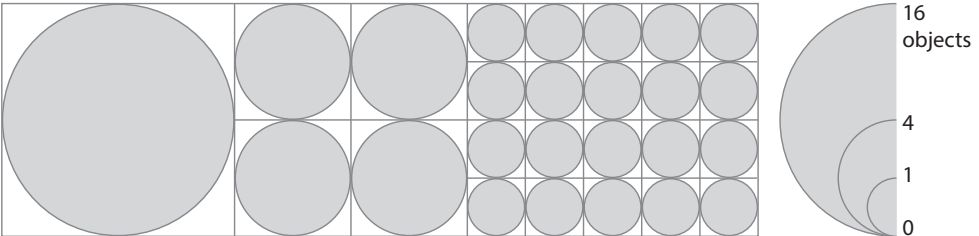


Figure 3. Symbol size relates well to the size of areal units, making proportional symbol maps capable of mapping non-standardised, absolute values (see Figure 2 for the underlying object distribution). Inspired by Slocum (2009).

the mapped attribute. However, several variants apply:

- Although the subject is controversial, perceptual scaling tries to adjust the symbol size to compensate the empirically tested tendency for underestimating the area of large symbols.
- The use of 3D-symbols like spheres or cubes allows scaling proportionally to symbol volume instead of area. Although volumes are estimated even more badly, this might be useful when large spans of data values have to be accommodated in the map.
- For data of extremely large or very small value ranges, data values might be classed and classes are assigned a set of ‘graduated’ symbols. While symbol sizes still represent the order of classes, symbols are not proportional to the magnitude of values any more. Thus additional information (e.g. in a legend) pointing to that fact is crucial for interpretation.
- At times, data is composed of several subgroups (e.g. total population by gender or age groups). To show this further subdivision, scaled diagrams can be used instead of plain symbols. Pie charts are often chosen due to their compactness.

Often, proportional or graduated symbols will overlap. While overall downscaling might be a solution, a small amount of overlap is acceptable. Using half-transparent, simple symbols like circles is a good strategy to cope with overlap as well. Web maps sometimes use cross-breeds of markers and proportional symbols: instead of permitting marker-overlap in small scales, nearby markers are aggregated into one symbol scaled to the number of markers it contains.

Isarithmic maps

Many ecosystem processes like climate regulation or air quality regulation take place in a spatially continuous manner. As a consequence, the related ES are also gradually varying over space. Isarithmic maps connect points of the same value (at certain intervals) by a line (=isoline) and are especially useful to map such smoothly changing ‘continuous field’ data. The most prominent examples of isolines are contour lines in topographic maps, connecting points of the same elevation. This concept can be used for all types of continuous fields. Isarithmic maps can be combined with areal colouring using continuous colour ramps. Alternatively, the areas between the isolines can be filled with a sequence of classed colours. A combination of isolines with analytical hill-shading intensifies the ‘surface’-character of the mapped phenomenon.

The construction of isarithmic maps requires surface data, commonly modelled as point grid or Triangulated Irregular Network (TIN). Grounded on a base value and an interval, isolines are constructed from the field model using spatial interpolation. Using, for example, a base value of 50 and an interval of 100 to display a surface with values ranging between 54 and 320, isolines of the value 150 and 250 will be the result. Since isarithmic maps emphasise the continuous, smoothly varying character of a phenomenon, it is advisable to use them for such phenomena even though the data is being provided as discrete samples. As an example, data on ecological vulnerability based on districts could be considered: while each district might have assigned a value indicating its vulnerability, local vulnerability might smoothly change over space, independently of sharp district borders. Depending on the intended message (‘objective representation of risk’ versus ‘hey governor,

you are responsible for this highly vulnerable district, act!') it might make sense to create a continuous vulnerability surface from polygonal data and utilise an isarithmic map for its communication. When following such an approach, it is important to use only standardised (relative) values from enumeration units for surface generation. Methods like pycnophylactic interpolation or area-to-point kriging, guarantee that the overall volume remains constant while the surface is smoothed.

Apart from the basic thematic mapping concepts described so far, there are numerous other techniques: Cartograms³, dasymetric maps, flow maps, animated maps⁴ or perspective views are just some examples for techniques meeting more specialised purposes.

Choosing an appropriate base map

A typical ES map consists of a topographic base map and one or more superimposed thematic layers showing the desired ES data. The base map provides the geographic reference to the ES data, informing the user on location while simultaneously providing a sense of the actual map scale. Depending on the used mapping framework⁵, there is often a choice between various base maps⁶. Some base maps can also be edited by the user to highlight or subdue certain object classes.

When choosing a base map, several aspects must be considered:

- Thematic support: The base map should support the thematic ES information;

³ <http://www.worldmapper.org/>

⁴ <http://hint.fm/wind/>

⁵ <http://tools.geofabrik.de/mc/>

⁶ <http://maps.stamen.com>

therefore it depends on the mapped ES topic, what kind of geographic features should be part of the base map. While some base maps focus on the street network⁷, others emphasise the terrain or highlight administrative boundaries. Users should carefully think about what kind of information is required to support the mapped ES topic.

- Visual prominence: Base maps provide ancillary information, thus their place is in the visual background. In a digital context there are two common concepts to accomplish this: A dark base map with bright and saturated thematic information on top or a light and unsaturated base map overlaid by darker and more saturated thematic layers.
- Visual density: At each scale level, the base map should have approximately the same visual density (number of shown features per area). If the thematic ES layers are rather complex, a base map with a rather low visual density (e.g. only coastline and country boundaries) should be chosen.

Generalisation

Due to scale limitations it is not possible to show all spatial objects with all their detail in the limited map space. Generalisation aims to represent the ES-information in a level of detail appropriate for a given scale, user group and use context. It is necessary in cases where the visual density in maps is increasing rapidly, symbols overlap or topological conflicts become evident due to graphical scaling. Figure 4 shows typical operations applied in the generalisation process. Although the application of some of those operators can be automated, it is the

⁷ <https://www.openstreetmap.org>

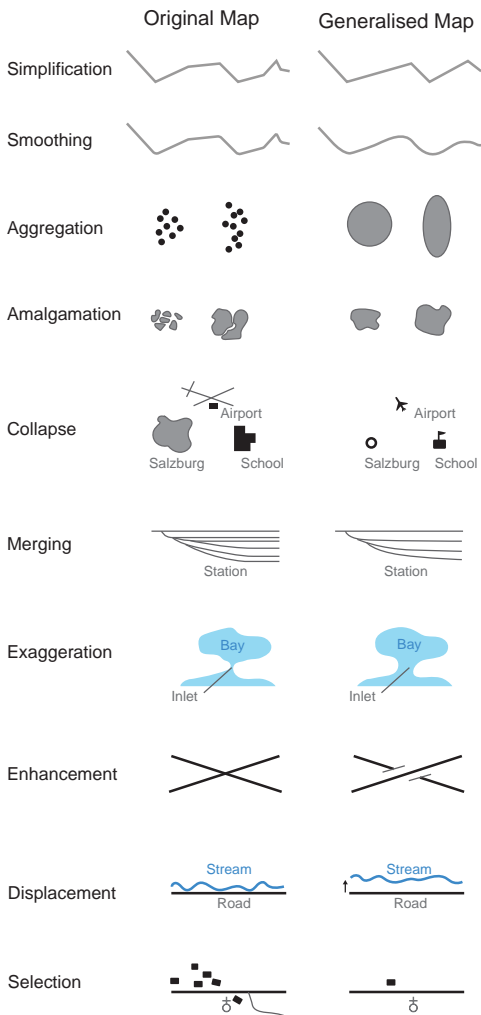


Figure 4. Typical operators for generalisation. Modified after Phillipe Thibault (in: Slocum, 2009).

responsibility of the map maker to decide on the relevance of specific ES information.

Conclusions

Map-makers can harness the broad knowledge base, experience and techniques available from cartography. ES-maps display highly complex human-environmental

systems, consisting of discrete and continuous features. This complexity should also be respectively reflected in the maps, which need to be logical, clear, understandable and well-designed.

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