5.7.2. National ecosystem service mapping approaches

Sharolyn Anderson, Alberto Giordano, Robert Costanza, Ida Kubiszewski, Paul Sutton, Joachim Maes & Anne Neale

Introduction

The creation of any comprehensive mapping instrument at the national level requires the careful consideration of a set of issues, with components that range from the scientific to the technical and from the economic to the organisational. Wealthier countries, such as the United States and many European countries, have a long tradition of national level cartography, analogue and then digital, dating back centuries - with the first comprehensive and 'modern' example being the Cassini Maps of 18th century France. In the United States, the 'National Map[1]' is the digital version and the continuation of efforts to map the country at a variety of scales and for multiple purposes was started in the late 1800s by the United States Geological Survey. One of many efforts to provide national maps for the US was the 'National Map' which includes data layers on elevation, hydrography, geographic names, transportation, structures, boundaries, ortho-imagery and land cover. Another example, the 'Australian National Map'[2], includes not only the same data layers as the U.S. national map but also layers on communication, environment, framework, groundwater, habitation, infrastructure, utility and vegetation.

For the world in general, the quality and quantity of information related to ecosystems and ecosystem services (ES) has been growing and it is expected that it will continue to do so as a result of increasing awareness of our fundamental dependence on natural capital and the value of ES. In this context, national maps may function as providers of reference cartographic data (see Chapter 7.1). Action 5 of the EU Biodiversity Strategy to 2020 calls for European Union's member states to map and assess the state of ecosystems and their services in their national territory. In the United States, a memorandum was issued in October 2015 directing Federal agencies to factor the value of ES into planning and decision-making activities at the federal level (see Chapter 7.1 for more details). The mapping of ecosystems is an essential first step in conducting an inventory of that portion of our common wealth that manifests as natural capital.

In this chapter, we briefly touch - from the perspective of the mapmaker - on a small set of topics related to the national mapping of ecosystems and ES. This discussion is by no means exhaustive and additional topics may be worth reviewing. Our objective is to inform the reader and to pique his or her curiosity; for further information, vast literature exists on all of these topics.

1 http://nationalmap.gov/

2 https://nationalmap.gov.au/

Peculiarities of national mapping scale and projections

The term "scale" is often used loosely and casually in lay conversation and may take different meanings depending on the traditions and conventions of individual fields. For example, some ecologists use the expression 'large scale' when referring to large areas. In cartography, scale is defined as the ratio between distances on the map and corresponding distances on the ground (see Chapter 3.1). Thus, a 1:1,000 map is at a larger scale than a map with a scale of 1:10,000, because the value of the ratio of the former (0.001) is larger than the value of the latter (0.0001). Thus, for a cartographer, a map at large scale shows a smaller area than a map at a smaller scale. Large scale maps show detail, as a map of one's backyard might be. Although guidelines for the classification of maps, according to their scale, have been developed and are in use, what constitutes a 'large' or 'small' scale map is a matter of convention. In classical handbooks of cartography, maps have been classified as 'large scale' (1:50,000 and less; for example, 1:25,000) or 'small scale' (1:500,000 and more, for example, 1:1,000,000), with medium scale maps somewhere in between. Individual countries may impose their own guidelines based on local situations, conventions and needs.

Although national maps are typically at a larger scale than maps showing continents or the entire world, it is the size of the country mapped that puts limits on the scale of its national maps and therefore on the level of detail for the cartographic representation. For example, a national map of ecosystems and ES for South Africa would be very different from a comparable map for Belgium, not only because ecosystems are more varied in the former than in the latter, but also because the level of detail at which thematic layers (land use, vegetation, infrastructures, etc.) that can be shown in the map of Belgium are much higher than in the South African example.

Concerning projections, the cartographic representation of real-world 3-D objects on a 2-D map necessarily introduces distortion (see Chapter 3.1). The larger the object mapped, the higher the amount of distortion. Regarding the national mapping of ecosystems and ES, we would argue that distortion in the size of the objects mapped and their relative distance are of special concern, as quantitative errors affect measurements, both linear and areal. Distortion in shape or direction may affect the cartographic representation and should be taken into consideration - the latter would be especially serious in case of nautical maps. The good news is that the way distortion varies across a map is predictable and tools exist (e.g., the Tissot's Indicatrix) to measure it accurately. Another good news is that all countries have established coordinate systems (which also describe projections, datum, etc.) for mapping their territories at various scales with the explicit purpose of minimising distortion.

Resolution

In the cartographic context, a concept related to 'scale' is that of 'resolution.' The two differ in that scale is measured linearly, while resolution is a measure of size. Thus, a remote sensing image at a resolution of 100 metres shows an area of 10 by 10 metres (assuming a square pixel). Such a resolution level would be coarser than an image at a resolution of 30 metres. This is relevant to the map-making process at any scale, including the national scale, in the sense that images at higher resolutions give the cartographer the option of making maps at larger scales. To return to the example made earlier, creating a map of one's backyard would be impossible using an image at a resolution of 100 metres, but feasible with an image at 1-metre resolution. Thus, the spatial resolution of available primary sources is one of the principal factors affecting map scale. One complicating factor is that, as it pertains to satellite imagery, the term 'resolution' has dimensions that are not spatial, including radiometric (e.g. how many levels of brightness; 6 bit, 8 bit, 12 bit, etc.), temporal (e.g. data acquisition frequency) and spectral (e.g. number of bands, bandwidths, etc.) resolutions. Note that the higher the resolution - in all of the above senses - the more expensive the primary source tends to be per size of the area mapped.

Generalisation

Cartographic generalisation, defined as the reduction of spatial and thematic detail needed to map the real world, is related to scale and resolution. In general, the smaller the scale of the map, the higher the amount of reduction needed (see Chapter 3.2). Note, however, that different levels of generalisation can be applied to the same primary source. Generalisation is a decision-making process measured along a continuum from low to high, with the high limited by the resolution of the image (recall the backyard example). This example also makes another important point: the cartographer works with the expert (in this case, an ecosystem expert) to determine the level of generalisation needed to answer specific research and/or policy-related questions (see Chapter 4.6).

Accuracy and currency of data

In cartography, 'accuracy' is defined as the closeness of a measurement to its true value. This is different from the definition of precision which pertains to the instrument used to make this measurement. To understand this idea, consider reading the latitude and longitude of the point at which you are standing from a GPS receiver. The position is estimated with a certain distance accuracy (for example, 2 metres); if the signal is scrambled- as might be undertaken in areas of conflict by the country that controls the GPS (US, Russia, China, etc.) - the unit will continue to indicate the same level of accuracy, even though its precision has been degraded. In addition to its spatial dimension, measured in quantitative terms, accuracy has another dimension which is particularly important in the context of the national mapping of ecosystems and ES. This is thematic accuracy, which is usually measured in terms of categories and therefore qualitatively - for example, consider a land cover layer in which a vegetated area is incorrectly classified as urban area. As it is for spatial accuracy, methods and tools exist for measuring thematic accuracy both at the level of feature and for the entire map.

Equally important is the currency of the information used. In addition to the obvious consideration that having up-to-date information is to be preferred to having outdated information, a crucial factor to consider is whether individual layers are current relative to each other. For example, consider deforestation which has progressed in some countries very quickly over the last 20 or 30 years: a layer of forested areas in, for example, Guatemala ca. 2000 would look very different than a corresponding layer from 2016. According to an old adage in cartography, a map is only as current as the newest data source that was used to create it. Creating a composite map from layers that show the situation on the ground at different dates would lead to erroneous conclusions. Note, though, that currency is of concern for certain types of information but not for others: for example, a geologic map does not need to be updated as frequently as a map of urban areas (see also Chapter 5.3).

In practical terms, accuracy and currency are dealt with in relative rather than absolute terms. This is the idea of 'fitness for purpose': because maps, especially at the national scale, are expensive to produce, update, maintain, distribute and, in legally litigious countries, the responsible agency can be brought to court for inaccurate representations, governmental cartographic agencies should and, usually do, use metadata to describe how the maps should be used, their limitations, accuracy levels and currency (in other words, their 'fitness for purpose'). Related to this discussion, in the last thirty years many countries and international organisations such as the ISO, have developed standards for the accuracy of geographic information. Note that, in the cartographic field, standards have been in long use, for example, the US National Mapping Accuracy Standard (NMAS) dates back to 1947.

Data Sources

There are myriad sources of data that can potentially inform and contribute to the production of maps for ecosystems and ES (see Section 4). A non-exhaustive list might include various types of satellite imagery, human population census data, agricultural productivity statistics, soil maps, vegetation maps, air quality measurements, biological census data, transportation and other infrastructure maps and climate station data and maps[3]. These data can be applied to the production of different kinds of ecosystems and ES mapping.

A key question to answer is how to structure and organise the representation of ES? This question applies to all cartographic representations ranging from the local to the regional, to the national and to the international. One approach is to create a separate layer for every ecosystem service (e.g. one layer for carbon sequestration, one for erosion control, one for spiritual values etc.). This approach is convenient from a taxonomic perspective but can be problematic, as variations in most of these services are driven by land cover proxy measurements (e.g. boreal forests sequester X kg/ha/year whilst deserts sequester Y kg/ha/year), but, in others, they vary as a function of spatial interactions with other spatially variable information (e.g. spiritual value will likely vary as a function of proximate population density, the income of that population and the spiritual values of the proximate population). Carbon sequestration provides a salient example of the relevance of these issues. It is increasingly regarded as a policy-relevant ecosystem service as a result of climate change. At a national level, authoritative, verifiable and valid ground-based measures of carbon sequestration which include direct measurements of vegetation and soil would likely be needed to produce a comprehensive, country-wide map of carbon sequestration.

Scientific accuracy, transparent methods of measurements and reliable and independent interpretation and dissemination of results would be needed to ensure the legitimacy of the process, both internally at the country level and in the international arena. Here, again, we run into the problem of economic costs, in the sense that valid and authoritative maps representing real and dynamic phenomena may be expensive to produce, maintain and update at the required levels of cartographic detail, accuracy and currency. For example, the 2010 United States Census of the Population cost approximately $13 billion to conduct, or over $40 per person counted and mapped. The degree to which large investments can be made by individual

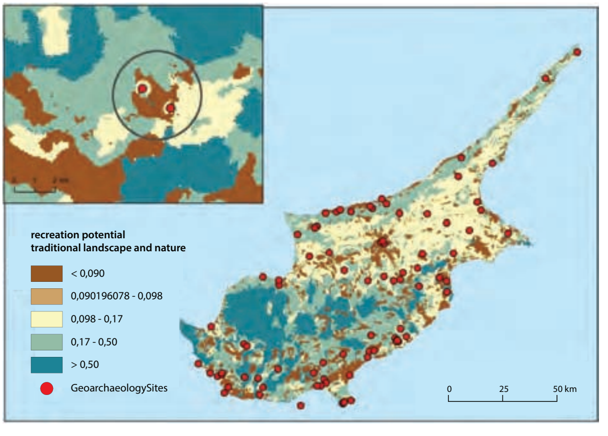
[3] http://biodiversity.europa.eu/maes

Box 1. Mapping ecosystem services at national scale in the European Union

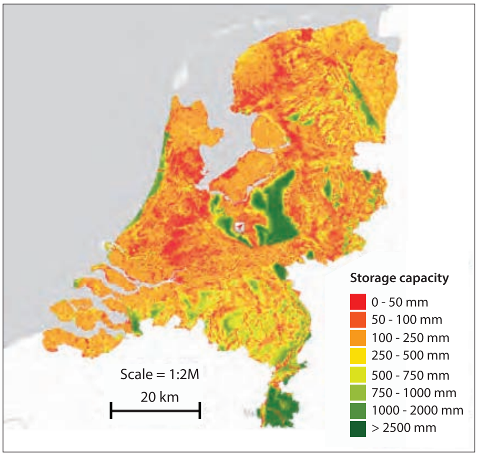
In the EU, countries have started initiatives to map their ecosystems and ecosystem services (ES) on their national territory. The principal objective is to create a national knowledge base on ecosystems which can be used for planning purposes such as the selection of areas for ecological restoration, the development of new infrastructure projects or land and water management. The European Commission is providing guidance to countries on how to map ecosystems and ES through the MAES initiative and collects information of countries on the biodiversity information system for Europe[4].

Two examples for Cyprus and The Netherlands illustrate nation-wide mapping of ES in the EU. Cyprus is an island in the Mediterranean Sea. The map illustrates the recreational potential of the traditional landscape and nature. The map was made in a training workshop where country officials from the ministry worked together with scientists to map recreational services on the island. The Netherlands create maps of ES which are publicly available via their Atlas of Natural Capital[5].

[4] http://biodiversity.europa.eu/maes
[5] http://www.atlasnatuurlijkkapitaal.nl/en/home|



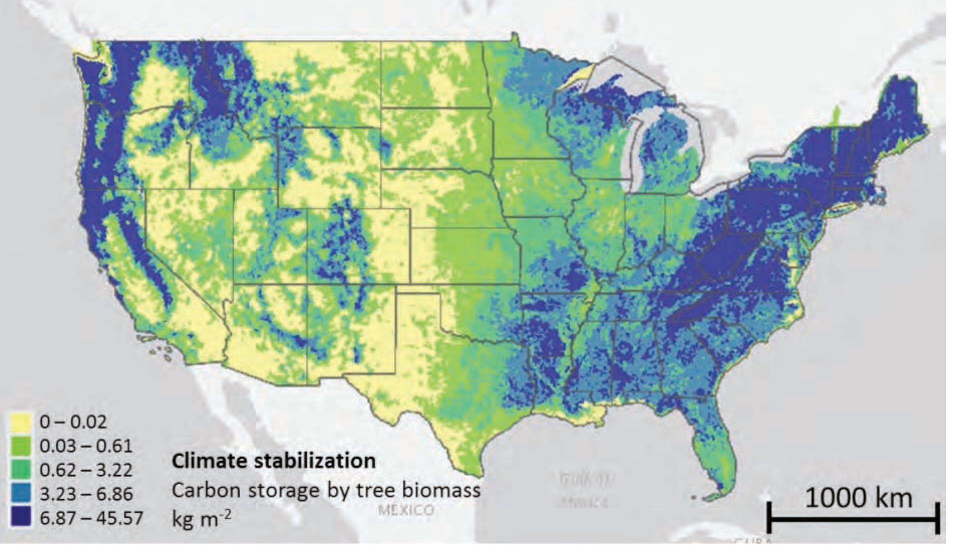
A map of recreation potential offered by the traditional cultural landscape and nature. This map is based on the recreation opportunity spectrum approach. The red dots are places of archaeological interest.



Map of the water storage capacity of soil (expressed in mm) in the Netherlands is derived from the Atlas of Natural capital which collects spatially explicit data of ES at national scale.

Box 2. Mapping ecosystem services at the national extent for the conterminous United States

In the US, the Environment Protection Agency leads a multi-organisation effort to develop and host a suite of nationwide maps of ecosystem services (ES) indicators and indices in EnviroAtlas[6]. This open access tool allows users to view, analyse and download a wealth of geospatial data and other resources related to ecosystem goods and services. More than 160 national indicators of ecosystem service supply, demand and drivers of change provide a framework to form decisions and policies at multiple spatial scales, educate a range of audiences and supply data for research. A higher resolution component is also available, providing data for finer-scale analyses for selected communities across the US. The ecosystem goods and services data are organised into seven general ecosystem benefit categories: clean and plentiful water; natural hazard mitigation; food, fuel and materials; climate stabilisation; clean air; biodiversity conservation; and recreation, culture and aesthetics. EnviroAtlas incorporates many data sources with multi-resolution (i.e., 1 m and 30 m) land cover data providing fundamental information. The data are updated at 5 year increments, subsequent to US National Land Cover Dataset updates.



This map shows the kind of data layers that are available in EnviroAtlas. For one of the indicators in the climate stabilisation category, this map shows the amount of carbon stored in the above-ground tree biomass. Like most of the national maps in EnviroAtlas, the data are summarised by medium sized watershed drainage basins known as 12-digit hydrological unit codes (HUCS). There are approximately 85,000 of these HUCS in the conterminous US, with each being approximately 104 km². Users of EnviroAtlas can also overlay demographic maps to gain the perspective of proximity and population dynamics of beneficiaries.

[6] https://epa.gov/enviroatlas

countries in order to map ecosystems and ES remain to be seen. Perhaps the solution is partnerships between countries - examples include the European Union's Joint Research Centre (JRC) and the United Nations Environmental Programme (UNEP) - as well as efforts by individual countries to create, maintain and share primary environmental data, including initiatives by US government agencies (for example the National Aeronautic and Space Administration (NASA) and the National Oceanic and Atmospheric Organisation (NOAA)).

Conclusions

For the public, national maps can provide benefits that exceed their costs of production, assuming the maps are soundly executed, regularly updated and distributed to the public at a reasonable cost. When mapping ecosystems and ES at national levels, careful consideration should be given in the very early planning stages to the scale, accuracy and level of generalisation needed for the explicit and specific purpose the map is intended to serve. This is crucial when one considers that the degree to which a country acquires up-to-date and reliable knowledge of its ecosystems and ES will determine its ability to manage them. Mapping should not only provide information on the quality and quantity of ES but also on their distribution among the population within a country which is key to issues of equality and social justice. Usually, the loss of ES has the greatest impact on the poorest communities which, as a group, are the first to feel the effects when those ES begin to disappear. In this sense, the mapping of ecosystems at the national scale is essential to understanding the magnitude and spatial distribution of such services and for the development of policies to protect and restore them.

Finally, we stress that the most important investment a country can make when addressing these issues is on its human capital. The creation, maintenance, update and distribution of a national mapping initiative require trained, skilled, committed and motivated personnel, with technological considerations important but secondary. The human capital should have the highest priority.

Further reading

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