LAND USE AND POPULATION DENSITY IN THE BALTIC SEA DRAINAGE BASIN: A GIS DATABASE

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ABSTRACT

We present a Geographic Information System (GIS) database of the large-scale drainage basin of the Baltic Sea. A set of GIS map layers were created and used to generate information on the current landscape characteristics and population distribution patterns in the drainage basin. Such data can be generated at the 92 meso-scale subdrainage basins, at the seven major subdrainage basins, and at the drainage basin as a whole, as well as by nations. Forests dominate in the drainage basin (48% coverage), followed by arable land (20%), and non-productive open lands (17%). Sweden and Finland contain 60 percent of total forest land, while most of the drainage basin's agricultural land is located in Poland. Wetlands cover roughly eight percent of the drainage basin. Of the 85 million people living in the Baltic Sea drainage basin, the vast majority (64%) live in the drainage areas of the Baltic Proper. Forty-five percent of people in the drainage basin live in Poland. About 22 million people (26%) live within metropolitan areas, 45 percent in towns or small cities, and 29 percent are rural. Nearly 15 million people live within a 10 km distance from the Baltic coast. Expanding to a 50 km distance from the coastline, we find 43percent of the total populated area and 31percent of the total population.

INTRODUCTION

The Baltic Sea and its drainage basin together make up a complex ecological-economic system. There are a multitude of linkages and feedbacks between the land-based ecosystems of the drainage basin, the sea-based ecosystems, and the human systems of the countries around the Baltic ([1],[2],[3],[4]). Such linkages have been addressed in the Baltic Drainage Basin Project, involving a small interdisciplinary research team of scientists from various institutions throughout Europe ([5]). A major emphasis of this project involves the eutrophication problem in the Baltic Sea.

In order to better understand and manage the ecological-economic processes at work in the drainage basin, it is necessary to understand the composition of the landscape as well as human distribution in the drainage basin. Furthermore, it is helpful to understand the spatial distribution of the landscape units as they relate to both sources and sinks of pollution into the Baltic Sea. Working at the drainage basin level in the Baltic region, however, poses some significant challenges.

The size of the drainage basin alone renders it extremely difficult to study. The Baltic Sea drainage basin covers more then 1.7 million km^2, over four times the surface area of the Baltic Sea ([6]). While many processes at smaller sub-drainage basin levels have been well studied, in such complex systems it is not justifiable to scale up results and apply them to the entire drainage basin ([7]). The political geography of the region is also formidable. Fourteen separate countries - Belarus, Czech Republic, Denmark, Estonia, Finland, Germany, Latvia, Lithuania, Norway, Poland, Russia, Slovakia, Sweden, and Ukraine - all lie fully or partially within the Baltic Sea drainage basin (Figure 1). Although scientific and political cooperation between these countries now is good, following the disintegration of the former USSR, obtaining compatible data for all 14 countries can be difficult ([8]). Finally, much of the data necessary for an integrated study of the drainage basin is available only at politically defined regions. Most data regarding human systems, for example, is collected at the nation, state, county, or municipality level. It is difficult to apply this data to an ecologically defined region such as a drainage basin without relying upon gross generalisations, particularly in cases where an administrative region is only partially covered by the drainage basin.

We have attempted to surmount these difficulties by creating a Geographic Information System (GIS) database for use in analyses of the Baltic Sea drainage basin. A set of GIS map layers were created and used to generate information on the current landscape characteristics and population distribution patterns in the drainage basin. According to our knowledge there has been no equally comprehensive picture of regional land use or human population distribution in the drainage basin prior to this study. There are seven map layers included in the database: Land Cover, Drainage Basin, Administrative Units, Population Distribution, Arable Lands, Pasture Lands, and Wetlands. This article begins with a brief description of these map layers, and how they were created. In the following section we present land use and population statistics for the Baltic Sea drainage basin and discuss our findings. We conclude with some suggestions for future research based on our results, as well as suggestions for improving upon the database. For readers unfamiliar with GIS, a brief description is available in Box 1.

THE BALTIC SEA DRAINAGE BASIN GIS DATABASE

The components of the 7 map layers in the GIS database, and procedures used in their creation are described below. A more detailed description of the technical procedures and the primary data sources used to create each layer, as well as an evaluation of data quality, is presented in Langaas and Sweitzer ([9]).

Land Cover

The Land Cover map (Figure 2) provides a general picture of the land use patterns which are found most frequently in the Baltic Sea drainage basin. The map is divided into cells representing the predominant land cover in one km^2 of real land area. The land cover classes contained in the map are: forest, inland water bodies, urban areas, glaciers, agriculture/open land, and a category called unclassified land which is either forest or agriculture/open land, but which can not be more specifically identified. The Land Cover map was created by combining two different sources of existing GIS data. A brief description of these sources and what the land cover definitions represent is useful for interpreting this map.

Forest data were extracted from the European Space Agency (ESA) Remote Sensing Forest Map of Europe ([10]). The forest classification in this map is defined as tree-covered areas and it does not distinguish between coniferous and deciduous forest stands. Shrub areas are not classified as forest. Inland water bodies, urban areas, and glacier locations were obtained from the ArcInfo version of the Digital Chart of the World (DCW) ([11]). The inland water bodies classification includes all lakes and reservoirs, as well as rivers and canals large enough to dominate a km^2 area. Smaller rivers and streams are not included in the Land Cover map. The populated place class includes settlements large enough to have a visible perimeter from the air. The maps used to create the DCW dataset were originally made for navigational purposes. Therefore, populated place locations were mapped not according to some population size criterion, but if they could be distinguished by a low- to medium-altitude pilot ([12]). In the Baltic region, populated place locations in the Land Cover map correspond very roughly to settlements with at least 200 residents. All coastal borders in the Land Cover map were also extracted from the DCW database.

The agriculture/open land classification in the Land Cover map includes agricultural land, pasture land, and 'unproductive' non-forest lands such as rural homesteads, non-utilised fields, shrub lands, and open mountaineous land. The agriculture/open land class was derived by combining the ESA forest map with the DCW data layers mentioned above. Non-forest land from the ESA forest map which does not intersect with land area classified by the DCW as water, glacier, or populated place is considered to belong to the agriculture/open land class.

Unclassified land area appears when the various map layers are combined to create the final Land Cover map. Unclassified land is an artifact of imperfect alignment between the ESA and DCW map layers. When combining the ESA and DCW layers together to create the final Land Cover map, areas of conflict occur along the lake shores and coastlines. These areas are identified as water by the ESA map and as land by the DCW map. Since these areas are not identified as water, glacier, or urban areas in the DCW dataset, which more precisely represents coastlines and lake shores, we assume they represent either forest or agriculture/open land. We are not able to determine, however, which of these two land class types they belong to and so have given them a separate classification. Unclassified land accounts for less than 2percent of the Land Cover map. Those who prefer to reassign the unclassified land cells into agriculture/open land or forests, can do so by means of various GIS techniques. One way is to use a majority filter and assign the dominating land cover type of the surrounding cells to the unclassified land cells.

We evaluated the accuracy of the land cover dataset by small-scale test areas of Sweden and Lithuania. We used a generalised Landsat TM based land cover data set for Sweden, and a digital GIS database for Lithuania, derived from topographic information.

Drainage Basin

The Drainage Basin map layer (Figure 3) was created so that data from the other map layers in the database could be extracted at the drainage basin level. The map was manually digitized from paper maps. The primary source map was designed by M. Falkenmark and Z. Mikulski ([13]). Two other maps were used for additional detail in the Danish Straits and the Kattegat sub regions. The Baltic Sea coastline used in our Drainage Basin map was extracted from the DCW dataset to assure exact alignment with the other data layers created for this study.

The Drainage Basin map is coded in such a way that it can be used to extract data at three different levels of aggregation. At the least aggregate level, 92 meso-scale sub-drainage basins are distinguished. In Figure 3, these divisions are shown separated by lines. In the intermediate level of aggregation the Baltic Sea drainage basin have been divided into seven major sub-drainage basins: sub-drainage basins of the Bothnian Bay, Bothnian Sea, Gulf of Finland, Gulf of Riga, Baltic Proper, Danish Straits, and Kattegat. These seven sub-drainage basins are identified by different shades of gray in Figure 3. Fully aggregated, the drainage basin map acts as a single unit.

Administrative Units

The Administrative Units layer is a map with a mix of municipality- and county-level administrative regions of the 14 countries falling fully or partially within the Baltic Sea drainage basin (Figure 4). The primary purpose for creating this map was to aid in developing a map of population distribution within the drainage basin. The administrative levels represented in the map were chosen based upon the availability of population statistics. The administrative units shown are at the smallest level for which statistics on urban and rural population were readily available. Because data availability differs from country to country in this region, the map contains a mix of municipality and county level districts. All administrative units are coded in such a way that the map can easily be aggregated to county or national divisions.

Derived Map Layers

Several of the maps included in the Baltic Drainage Basin GIS database were derived using a combination of statistical and spatial data sources. The derived map layers are: Population Distribution (Figure 5), Arable Lands and Pasture Lands combined (Figure 6), and Wetlands (Figure 7). For these particular themes, either no GIS data existed for a substantial portion of the drainage basin area, or GIS datasets were available but of unacceptable quality for use in this study. Rather than forgo including these thematic layers in our database, we relied on statistical data to provide estimates of quantity (i.e. number of people, wetland area, etc.), and used other map layers from the database to estimate the distribution of the quantities through space.

The population distribution map combines the following primary map layers and statistics; Administrative units, Land Cover, and Population Statistics on urban and rural population. For each administrative unit, the urban population was assigned to the urban areas' grid cells assuming equal density. The rural population was alloted to the rural land cover classes, Agriculture/open land, Forest, and Unknown Class, under the same assumption. We admit that the assumption of equal density does not provide a true picture of reality, but still, the division of the human population into urban and rural and their appointment according to urban and rural land cover classes (and exclusion of inhabitable land) is superior to the conventional approach which only uses gross population and undifferentiated population density assumptions. For cartographic reasons the resulting GIS-data set was filtered twice to make the map in Figure 5, using a low pass filter. Furthermore, we tested the Single Objective Multi-Criteria Evaluation model to distribute the rural population according to other criteria than only land cover ([14]). This approach was developed for the three Baltic States using proximity to roads, railroads, and major towns as other determining factors. To make the model as realistic as possible, these factors and the rural land cover classes were assigned with various weights by local experts ([15]). We plan to extend this approach to the level of the entire watershed.

The Arable Land and Pasture Land map (Figure 6) was made in a similar manner. Statistics on arable and pasture lands were collected from a wide variety of sources, mostly at the county level. The area of the Agriculture/open land class was calculated from the land cover map for each of the associated agricultural statistical units. The ratio of the statistical area of arable and pasture lands to open land area was assigned to the agriculture/open land 1 km^2 grid cells. These ratios, and the sums, were found to be in the range 0-1 as anticipated, with a few minor exceptions. These ratios were further aggregated to 10 km x 10 km grid cells.

The lack of readily available accurate information on the amount and distribution of wetlands in the Baltic drainage basin area is noteworthy in light of the interest and importance of the capacity of these ecosystems to filter and retain nutrients ([16]). There exists only one scientific database of wetlands that covers the entire Baltic Sea drainage area ([17]). This data is a global database with a resolution of 1 deg. x 1 deg.

Three data sources were used to construct a more detailed wetland distribution map (Figure 7). Wetland acerage was obtained from statistical sources on various administrative levels in the 14 countries of the drainage basin. Generally, wetland statistics were only available on more aggregated levels than agricultural statistics, which may reflect societies' perception of the relative economic importance of agricultural land versus wetlands. Within the Land Cover layer of the DCW there is a category named Undifferentiated Wetlands. When this category was compared with more detailed information from small scale samples of actual wetland distribution it was found that it could not be used as the sole data source due to inferior quality. However, comparisons with national atlases showed that the distribution was of a sufficient quality to justify combining it with statistical information. We applied the same ratio approach as used for estimating the distribution of agricultural land. We decided to aggregate the 1 km^2 ratio grid cells to 50 km x 50 km cells. Although the derived wetland map has a coarser resolution than the other derived map layers it is, to our knowledge, the best available digital dataset of the distribution of natural wetlands in the Baltic Sea drainage basin.

The quality of the resulting derived map layers is largely dependent upon how accurate statistics are and how consistent statistical definitions are between the 14 drainage basin countries. Another crucial factor affecting the quality of the derived map layers relates to how closely our assumptions about distribution match reality. Because our methods do rely heavily upon these assumptions, the accuracy of the derived maps is likely to be lower than maps created from spatial data sources alone, such as satellite images. We believe, however, that this method provides us with a more accurate description of these particular characteristics of the drainage basin than any study to date. For a detailed description of the methods used to create each derived map layer, the reader is referred to Langaas and Sweitzer (9).

USING THE GIS DATABASE FOR ANALYSIS

There are numerous ways in which the map layers in this database can be combined to generate new results. In this article we use the maps to generate basic statistics on land use and population in the drainage basin. These results are reported below. In addition, we present results relating the distribution of land cover and population as a function of distance from the coast, and discuss future applications of the GIS database.

Land Use and Population in the Baltic Sea Drainage Basin

The drainage basin map layer was overlaid with other map layers in the database in order to generate statistical information on land use and population in the drainage basin (Table 1, 2). Data are presented here for each of the seven major sub-drainage basin divisions (see Figure 3), along with totals for the entire drainage basin. Data can also be generated at the 92 meso-scale sub drainage basin level. Land use in the drainage basin is shown in both area and percentage figures (Table 1). Forests dominate the landscape in the drainage basin (48% coverage), followed by arable land (20%), and non-productive open lands (17%). Most of the forests are found in the Bothnian Bay (23%) and the Gulf of Finland (27%) drainage basins. The majority of arable land, pasture land, and populated area are found in the Baltic Proper drainage basin (64%, 64%, and 48% respectively). The majority of inland water (53% of total inland water surface area) is located in the Gulf of Finland drainage basin. Wetlands cover roughly eight percent of the drainage basin and are most prominent in the northern regions. The majority of wetlands are found in the Bothnian Bay drainage basin (41%). The Bothnian Sea, Gulf of Finland and Baltic Proper drainage basins each have between 16 and 17 percent of the total wetlands, while the remaining drainage basins contain fewer than six percent of the wetlands.

Population distribution is detailed in Table 2. According to our results, about 85 million people live in the Baltic Sea drainage basin. Of these, the vast majority (64%) live in the drainage areas of the Baltic Proper. The drainage areas of Gulf of

Finland has the second largest population (15%). The remaining drainage basins each contain less than seven percent of the total population. Twenty-six percent of the total drainage basin population (about 22 million people) live within metropolitan areas (population > 250 000). Forty-five percent of the total population live in towns or small cities (population between 200 and 250 000), and 29 percent are considered rural (population < 200).

The database was also used to develop a national composite of population and land use in the Baltic Sea drainage basin (Table 3). Seventy-nine percent of the total drainage basin land area is covered by Sweden, Russia, Poland, and Finland (24%, 19%, 18%, and 18% respectively). Forty-five percent of people in the drainage basin however, live in one country - Poland. The Russian population in the drainage basin accounts for 12 percent of the total while 10 percent are Swedish. The other countries each account for less than six percent of the total drainage basin population. Sweden and Finland contain the most forest land in the drainage basin (35% and 25% of total forest land respectively), while most of the drainage basin's agricultural land is located in Poland (41% of the arable land and 39% of the pasture lands). The Russian portion of the drainage basin contains the largest surface area of inland water (36% of total) followed by Sweden (28%) then Finland (24%).

Land Use and Population as a Function of Distance from Coast

The further from the coast or from rivers eutrophying substances are released, the more likely they are to be absorbed through biogeochemical and ecosystem processes and prevented from entering the Baltic Sea. High population concentrations, agricultural lands, and urbanised land are important sources of the nutrients which contribute to eutrophication. Wetlands, forests and inland water bodies can act as natural sinks for nutrients as well as other pollutants. Given this, it is interesting to determine the landscape characteristics of the drainage basin as a function of distance from the coastline and rivers. At this point we are able to discuss landscape patterns as they relate to the coastline only, since the database does not contain a detailed map of river systems. Looking at human development patterns in relation to the coastline, we gain some insight into how effectively ecosystem services ([18]) are being utilized to prevent eutrophication.

Using the Land Cover and Population map layers and an adjusted map of the drainage basin it was possible to determine the characteristics of the drainage basin as they relate to distance from the coast (Table 4). At its furthest point, the drainage basin is nearly 650 km away from the Baltic Sea shoreline. Land cover and population of the drainage basin were assessed at 10 km intervals extending away from the coast. It was found that while most of the land use classes are distributed fairly evenly throughout the drainage basin, population - particularly urban population - is heavily concentrated toward the coast. Within a 10 km distance from the Baltic coast, for example, we find 27 percent of the populated area and 18 percent of the total drainage basin population - nearly 15 million people. Of these, 90 percent are concentrated in urban areas. Also within this area we find eight percent of the total arable land, five percent of the pasture land, five percent of the forests, and two percent of the inland water bodies. (We did not consider the wetlands data to be of sufficient quality to warrant inclusion in this analysis.) Expanding to a 50 km distance from the coastline, population remains the dominant feature of the landscape. In this zone we find 43 percent of the total populated area and 31 percent of the total population (over 26 million people). Of this population, 83 percent are urban. Additionally, 23 percent of the total arable land, 17 percent of the pasture land, 20 percent of the forest, and 10 percent of the inland lakes are found within a 50 km distance from the coast.

CONCLUSIONS AND FUTURE APPLICATIONS OF A BALTIC SEA DRAINAGE BASIN GIS DATABASE

In this article we have presented a recently developed GIS database covering the large-scale drainage basin of the Baltic Sea. It has been created using existing digital data from a wide range of national and international data producers and sources. We recognize that the quality of the data and the resolution varies within the data base, and also between countries for the various themes. Still, this GIS database is, as far as we know, the best existing for the region. In our opinion it is difficult to implement sustainable policies in the Baltic Sea drainage basin without comprehensive information on the ecological resource base, and the distribution and scale of the human population and economic activities using this resource base. We have through this database derived basic statistical and cartographic information not previously available (see Figures and Tables). The information on the watershed level, presented here, was largely unknown when the 18 billion ECU Baltic Sea Joint Comprehensive Environmental Action Programme was launched a few years ago, with the purpose to “assure the ecological restoration of the Baltic Sea“ emphasizing the reduction of nutrient pollution ([19]). Using this database, additional and complementary analyses are presently performed by the authors and collaborating research groups, such as

* statistical analysis of relationships between nutrient outflow and land cover
* modeling of nutrient retention
* quantitative assessments of ecological services of the Baltic Sea drainage basin
* ecological footprints and carrying capacity analyses
* terrestrial net primary production estimates

The database we have developed will be distributed as public domain data ([20]), and as a consequence we envisage the list of its application to increase substantially. It is our hope that the availability of this database will assist in attempts to analyse the drainage basin as a coherent ecological-economic unit, as well as stimulate the development of new and improved GIS map layers for the Baltic Sea drainage basin, something which has been stressed by the regional planning community ([21]). An international project is presently working toward such a goal, involving HELCOM, UNEP/GRID-Arendal and GRID-Warsaw, Finnish Environment Agency, Swedish Space Corporation and Swedish Meteorlogical and Hydrological Institute, and the Basic Geographic Information of the Baltic Drainage Basin (BGIS) project ([22]).

Figure legends

Figure 1. The 14 countries of the Baltic Sea Drainage Basin, Belarus (BY), Czech Republic (CZ), Denmark (DK), Estonia (EE), Finland (FI), Germany (DE), Latvia (LV), Lithuania (LI), Norway (NO), Poland (PL), Russia (RU), Slovakia (SK), Sweden (SE), and Ukraine (UA).

Figure 2. The land cover of the Baltic Drainage Basin. See also Tables 1 and 3.

Figure 3. The Baltic Drainage Basin is coded in such a way that it can be used to extract data at three different levels of aggregation. At the least aggregate level, 92 meso-scale sub-drainage basins are distinguished, shown separated by lines. The intermediate level of aggregation divides the drainage basin into the seven major sub regions of the Baltic Sea: Bothnian Bay, Bothnian Sea, Gulf of Finland, Gulf of Riga, Baltic Proper, Danish Straits, and Kattegat. Fully aggregated, the drainage basin map acts as a single unit.

Figure 4. Municipality and county level administrative regions of the 14 countries of the Baltic drainage basin. This map was created to aid in developing a map of human population distribution within the drainage basin.

Figure 5. Population density in the Baltic Drainage Basin. See also Table 2.

Figure 6. Agricultural land, arable and pasture, in the Baltic Drainage Basin. The grid cells correspond to 10 km x 10 km. See also Tables 1 and 3

Figure 7. The wetland distribution in the Baltic Drainage Basin. The grid cells correspond to 50 km x 50 km. See also Table 1.

BOX 1: THE GIS APPROACH

A Geographic Information System (GIS) is software and hardware able to manage and analyse georeferenced data and attribute data together. Attribute data refers to any type of descriptive or statistical data linked to geographical features. Georeferenced data is associated with geographic co-ordinates, which give the data some location in space. Data in a GIS are stored as map layers and output is usually in the form of maps or data tables. What distinguishes GIS maps from paper maps or maps generated with computerised cartographic programs is their link to information contained in a database. In this sense, GIS map layers may be thought of as "higher-order" maps ([23]).

The ability to integrate spatial and attribute data enables a GIS to not only visually represent landscape features, but to associate these features with a host of descriptive and spatial information and use this information together in analysis to generate new information. For example, a GIS map of lakes in Sweden can show the distribution of lakes throughout the country just like any map. In addition, the same map could be used to provide information on mean depth, mean seasonal temperature, benthic conditions, acidity level, nutrient content, species composition, income generated from tourist visits, number of households along the shoreline, etc. for each lake. This map could then be combined with other GIS map layers in a spatial analysis to generate new information. The analysis may be quite straight forward. For instance, in combination with a land use map, it could be used to identify all the lakes with farmland of more than 100 hectares within 3 km of the shoreline. Or, in combination with several map layers, it could be used to identify the key landscape characteristics related to successful nesting of a threatened waterfowl species. GIS analyses can also be quite complex, utilising a host of spatial modelling techniques.

Technically, GIS software packages may be fundamentally different from one another. Any GIS, however, will contain a series of operations which allow it to perform three primary functions: present the current data, find new patterns in current data, and calculate new information ([24]). These operations can be grouped into four functional categories. First, a GIS will have retrieval, classification, and measurement functions. These functions can be used to show patterns in data or present data in an illuminating way. They have the ability to answer questions, generalise data according to some specified category, calculate area, perimeter, distance, etc.. The second group of GIS functions are the overlay operations. Overlay operations, allow the user to combine several map layers using either arithmetic operators such as addition, subtraction, multiplication, etc. or logical operators such as "and", "or", "yes", and "no". Thirdly, GIS systems have neighborhood functions. Neighborhood analyses are useful for determining the characteristics within user defined locations or for calculating distance or travel time between various locations. Finally, any GIS will be able to perform a series of connectivity functions. Connectivity functions involve moving through space and accumulating quantitative or qualitative totals. They may be used for a variety of analyses, from defining contiguous areas or buffer zones, to modelling water flow patterns, estimating the impact of an oil spill, or determining the fastest traffic route through a city at rush hour. Used together, these operations have a large range of analytical capabilities which makes GIS a powerful tool in any study where geographic location is an important characteristic (22).

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[20]. The GIS database described here will be made available to the public on CD-ROM and through Internet. In addition to the GIS data in some common GIS formats, cartographic information products will be made available in standard graphical file formats, such as Postscript and GIF. Those interested in further information should contact the Information Manager, UNEP/GRID-Arendal, P.O. Box 1602 Myrene, N-4801 Arendal, Norway.

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