Spatial Characterization of the Baltic Sea Drainage Basin and Its Unmonitored Catchments
Author(s): Fredrik Hannerz and Georgia Destouni
Source: *Ambio*, Vol. 35, No. 5 (Aug., 2006), pp. 214-219
Published by: Springer on behalf of Royal Swedish Academy of Sciences
Stable URL: http://www.jstor.org/stable/4315725

Fredrik Hannerz and Georgia Destouni

Spatial Characterization of the Baltic Sea Drainage Basin and Its Unmonitored Catchments

We present an updated, harmonized hydrologic base map of the entire Baltic Sea Drainage Basin (BSDB), including 634 subdrainage basins. The updated map has a level of detail approximately 5 to 10 times higher than the current standard and includes various spatial-aggregation possibilities of relevance for water management. All 634 subdrainage basins and their various spatial aggregations are characterized in terms of population, land cover, drainage density, and slope. We identify, quantify, and characterize, in particular, drainage basins that are unmonitored with regard to the combination of water-flow and nutrient-concentration measurements needed to monitor coastal nutrient and pollutant loading. Results indicate that out of a total BSDB population of 84 239 000 in 2002, 24% lived in unmonitored coastal drainage basins that cover 13% of the total BSDB area. A more detailed analysis of Swedish catchments indicates that Sweden has a particularly large proportion of unmonitored coastal catchment areas (20% of the total Swedish area) with high population pressures (55% of the total Swedish population), when compared with average conditions for the whole BSDB. In general, the investigated characteristics of unmonitored coastal basins vary and differ largely from those in adjacent monitored drainage basins within the BSDB.

INTRODUCTION

Once of more local character, scientific studies of inland drainage to the Baltic Sea now involve all its national and international catchments (1–4), to assess both impacts of and abatement measures for various water-quality problems, such as high nutrient and pollution loads to the coastal and marine waters. Deterioration of the Baltic Sea and inland waters within its drainage basin because of human activities is forcing expensive action programs from the local to the international scale. International cooperation and transboundary-scale applications are likely to increase in the near future, as the European Commission (EC) Water Framework Directive (5) forces water managers at all levels to focus on basin-scale analysis, including basins shared with other countries. Area-wise, two-thirds of the drainage-basin districts delineated according to the EC Water Framework Directive will be international (6), and this situation is similar for areas that drain to the Baltic Sea. In this situation, relevant, up-to-date, and harmonized spatial environmental data and information are needed for development, design, and evaluation of national and international management plans and associated research.

For scales such as the entire Baltic Sea Drainage Basin (BSDB), however, supporting spatial data may be rare and seldom or never updated. The very first multithematic and readily accessible Geographic Information System (GIS) database for the BSDB, the Global Resource Information Database (GRID) (7), was developed in 1992, on the basis of a cutout of existing global environmental spatial data. A second and more ambitious step was taken within the Baltic Drainage Basin Project (8) that resulted in the Baltic Sea Region GIS, Maps and Statistical Database (9, 10), which is still the most extensive environmental spatial database. It covers the area with eight layers of data (administrative units, arable land, coastline, land cover, pasture lands, population density, drainage basins, and wetland distribution). In 2001, the land-cover data set BALANS was published (11), as well the administrative base map MapBSR (12), developed by the national mapping agencies around the Baltic Sea.

The freely accessible spatial data in the Baltic Sea Region GIS, Maps and Statistical Database (9) have proved to be widely appreciated and used. This database was published openly on the Internet in 1995 and, starting from March 2000, usage statistics have been systematically collected. GIS-formatted data were downloaded 36 000 times between March 2000 and August 2004 (13) for use in a wide set of scientific, commercial, and educational applications (14). Of this total number, the drainage-basin delineation, which contains 81 drainage basins, amounted to 3400 downloads, with a wide distribution and use in the hydrologic science community (1–3). This wide use, however, appears to depend more on the free data accessibility than on data quality; the original data were digitized from a paper map presented by Falkenmark and Mikulski (15), with an unknown scale and projection and an indicative scale of approximately 1:5 000 000. In some regions, drainage basins were aggregated to fit the purposes of marine modeling, whereas others were not aggregated. Even a quick visual inspection of the data reveals a low degree of harmonization and positional accuracy of water dividers. Therefore, an update and enhancement of the definition of the boundaries of the BSDB and its subbasins are due.

The network for water-flow and nutrient-concentration monitoring is extensive in the BSDB (4, 16, 17), compared with many other regions of the world. Even in the BSDB, however, a limited independent database is available for quantification of the variability of driving forces for nutrient and pollutant transport from land to coastal waters around the Baltic Sea. Such driving forces include, for example, population, land use, and topography. Smith et al. (18), for instance, suggested recently a close empirical relation between drainage-basin population and coastal nutrient loading. However, so far, the only scientific assessment (9) of population distribution within the BSDB available for establishment and testing of such correlations is based on data and interpretations from around 1990.

The main aim of this paper is to identify and, to the degree possible on the basis of currently available data, fill out environmentally important spatial-data and information gaps regarding the BSDB, by *i)* development of an up-to-date hydrologic base map of the BSDB, including several aggregation possibilities suited for various hydrologic and environmental modeling and mapping applications; *ii)* providing a relevant distribution of 2002 population statistics among derived drainage basins, marine areas, countries, and coastal buffer zones; *iii)* providing important data for poorly characterized unmonitored catchments; and *iv)* publication of derived spatial data in the public domain.

DATABASE UPDATES AND METHODS

We present here the development of a freely accessible updated spatial database of the whole BSDB and its subbasins, marine areas, and river-basin districts (Fig. 1), at a nominal scale of approximately 1:1 000 000, by integration and processing of reported spatial and nonspatial data for the BSDB and Europe (6, 9, 19–25). Attribute data, added to all the subdrainage basins in the database, enable a user to aggregate subdrainage and drainage basins and characterization data on different management-relevant hydrologic scales, up to the BSDB itself.

Updated Delineation of the BSDB and Its Subbasins

Hiederer and de Roo (19) presented a European flow network and associated catchments derived from a 1-km digital elevation model and a 1:1 000 000-scale river network. The use of a mapped river network ensures that erroneous drainage-basin delineations caused by uncertainties of flat terrain are avoided. The data set, therefore, has some comparative advantages relative to the recent drainage-basin delineation by Vogt et al. (26), which is based only on high-resolution elevation data. We made use of the catchment-boundaries data (19) by extraction of all drainage basins that drain into the Baltic Sea, on the basis of the sea-boundary definition provided by Sweitzer et al. (9). All polygons smaller than 6 km^2, many of which are artifacts of the semiautomated raster-based approach, were deleted or merged with bordering drainage basins, to decrease the large number of small features.

Furthermore, we introduced coding to aggregate individual drainage basins into larger hydrogeographic units. These units include *i)* river-basin districts for water management in European Union member states according to the EC Water Framework Directive, by use of spatial data presented by Nilsson et al. (6) and available updates of river-basin district delineations as provided to the EC per July 2004 (27); *ii)* the seven large marine areas of the Baltic Sea (Bothnian Bay, Bothnian Sea, Baltic Proper, Gulf of Finland, Gulf of Riga, the Danish Straits, and Kattegat), by use of the spatial definition of Baltic Sea marine areas presented by Sweitzer et al. (9) and its adaptation to the later definition presented by HELCOM (20); and *iii)* a combination of national border and marine areas. We named major catchments according to designations in the European Environment Agency (EEA) Waterbase (17).

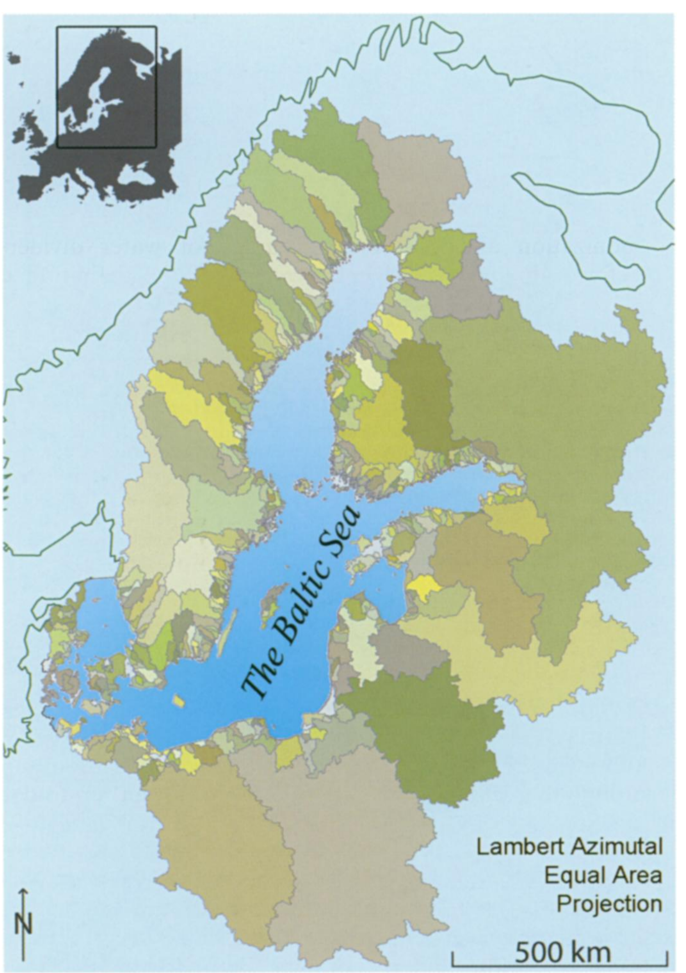

Figure 1. The new delineation of the Baltic Sea Drainage Basin (BSDB) with 634 drainage subbasins greater than 6 km^2.

Characterization of Unmonitored Catchments in the BSDB

One main aim of the present study is to use the developed updated BSDB database to test common catchment-homogeneity assumptions in hydrologic, pollutant, and nutrient transport. For this purpose, we distinguish between drainage basins that are (monitored basins) and basins that are not (unmonitored basins) covered by available observation stations for systematic monitoring of water-flow and nutrient-concentration data. Among different possible water-quality measures, we choose here to consider nutrient concentrations because they are the most closely monitored among different types of pollutants in the BSDB.

Stålnacke et al. (4) made a compilation of monthly runoff and nutrient-concentration data for 110 rivers in the BSDB by use of databases from national environmental agencies and the Swedish Hydrological and Meteorological Institute. These data are now disseminated via the Baltic Environment Database (16) and have been the basis for several recent nutrient-transport quantifications (3, 4, 28). A more comprehensive and geo-referenced overview of the full range of available national water-quality monitoring within the BSDB, with exception for Russia, Belarus, and Ukraine, can be found via the EEA Waterbase (17). By use of the 162 most-downstream water-quality monitoring stations within the BSDB from EEA Waterbase (17) and the three most-downstream stations along the Neva, Luga, and Pregola rivers in Russia (S. Bosova pers. comm.), the extent of monitored drainage basins (i.e. the drainage area upstream of monitoring locations) was identified by use of a distributed hydrologic-routing model based mainly on topography. Digital elevation data from the Shuttle Radar Topography Mission (29), which had 90-m resolution up to 60°N and 1000 m above, were used to derive flow directions for the flow routing. In addition, the updated database on drainage basins (this paper) and river-network data (30) enabled us to assign flow in the correct direction in areas characterized by low topographic gradient. We can then define and identify unmonitored basin areas of the BSDB catchments and whole catchments not draining into any of the available water-flow and nutrient-concentration monitoring stations (Fig. 2).

Unfortunately, so far no comprehensive compilation of detailed national station locations for water-flow monitoring within the whole BSDB exists; available databases suffer either from incomplete coverage or from lack of geo-referencing. However, detailed information from different types of monitoring stations in Sweden revealed clearly that flow and substance (here nutrient) concentrations are often not measured at the same locations (Fig. 3), even though colocated and simultaneous measurements of both are needed for estimation of mass loading of pollutants and nutrients into downstream waters and the sea. The detailed Swedish example indicates that the BSDB drainage area covered by nutrient-concentration monitoring (Fig. 2) may overestimate the drainage area covered

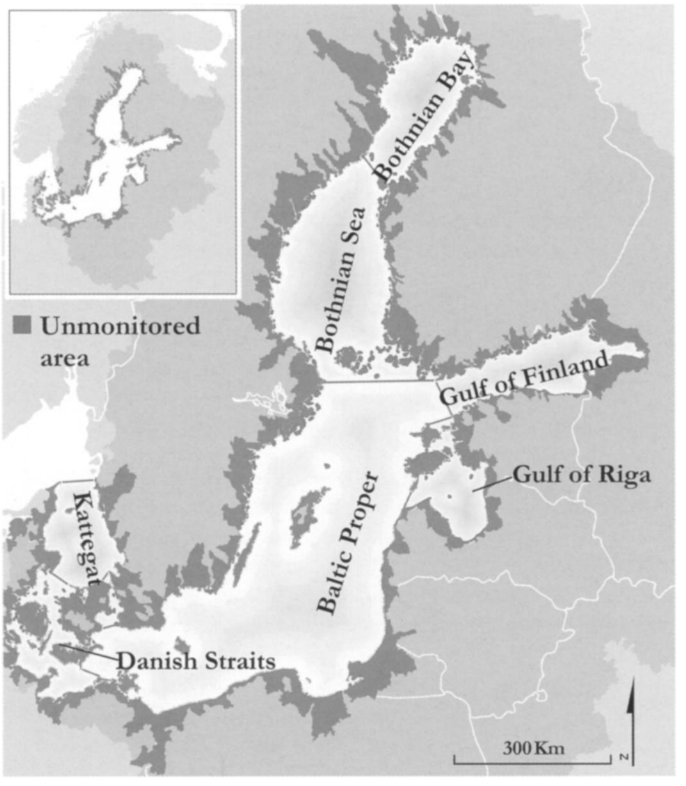

Figure 2. Monitored (light gray) and unmonitored (dark gray) catchments in the BSDB with regard to nutrient-concentration monitoring. These unmonitored catchments correspond to 11% of the area and include 21% of the population of the BSDB. The seven marine areas of the Baltic Sea are also shown.

by combined water-flow and nutrient-concentration measurements, as needed for accurate monitoring and quantification of downstream nutrient and pollutant mass loading. We, therefore, use the more detailed monitoring-station data for Sweden (Fig. 3), for which comprehensive and geo-referenced data are available for both water-flow and nutrient-concentration monitoring locations (17, 31), to more accurately estimate the extent and role of unmonitored catchment areas in Sweden, by use of the same modeling methodology as for the whole BSDB.

Population and Other Parameter Distribution in the BSDB

With the developed updated delineation of the whole BSDB and its subdrainage basins, and with recently presented distributed-population data (22, 32), we develop and present updated population statistics for the BSDB and its subbasins. The population data from Landscan (22, 32) uses yearly population statistics, mostly on second level below national, and distribute it over the landscape by use of a modeling approach that follows a set of assumptions on settlement preferences. Ideas from Sutton (33) on how to relate population distribution to global nighttime imagery of light emissions are combined with additional factors, such as distance from major roads, elevation gradient, and land cover, to calculate population density in a specific area. The resolution of the resulting population database is 30 × 30 arc seconds.

Population statistics for the BSDB and its subdrainage basins were, for the present database, calculated with a GIS by use of Landscan data for 2002 (22). Total population, population density, and share of total BSDB population were calculated for drainage basins, for aggregated drainage basins draining to the seven marine areas (Bothnian Bay, Bothnian Sea, Gulf of Finland, Baltic Proper, Gulf of Riga, Kattegat, and the Danish Straits), for the shares of all BSDB countries, and for six buffer zones along the Baltic Sea coast at different

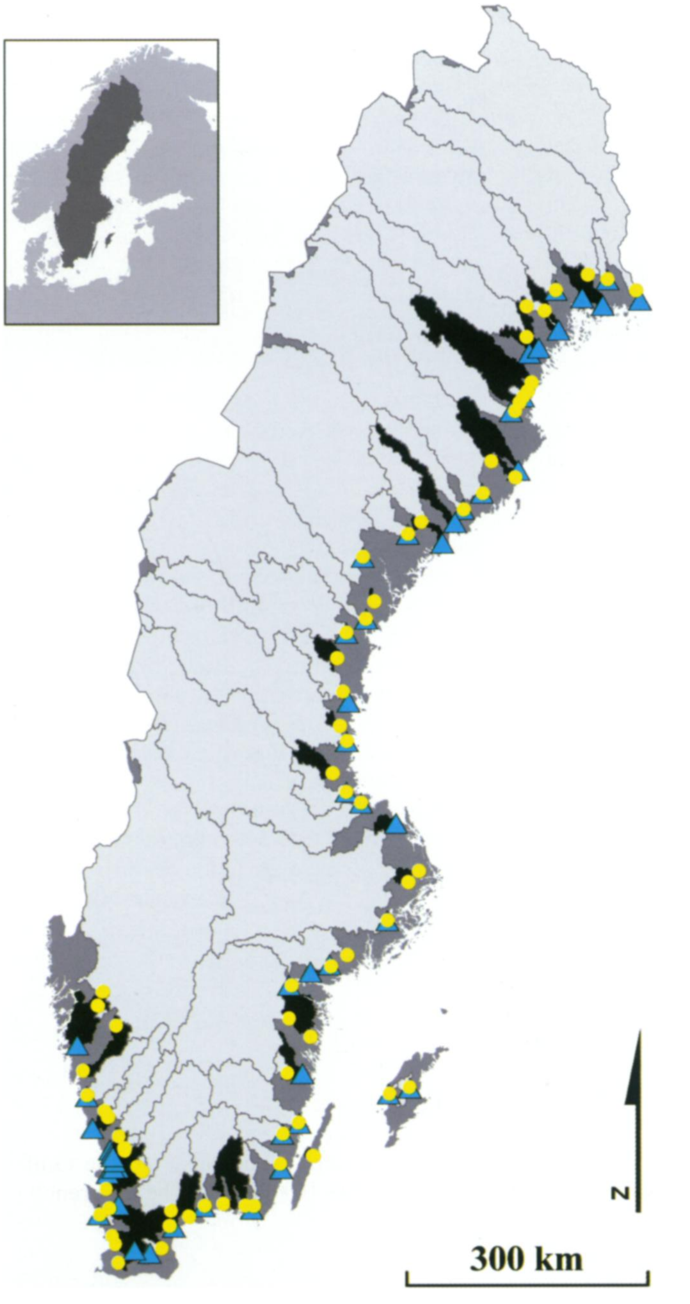

Figure 3. Monitored (light gray) and unmonitored (dark gray and black) catchment areas in Sweden with regard to both water-flow and nutrient-concentration monitoring. Locations of the most-downstream stations is shown for water-flow (yellow dots) and nutrient-concentration (blue triangles) monitoring. Black color indicates areas that are only monitored with regard to either water flow or nutrient concentration. The monitored (light gray) areas correspond to 80% of the total area of Sweden but include only 45% of the Swedish population.

distances from the coast (in kilometers): 0 to 10, 10 to 50, 50 to 100, 100 to 200, 200 to 300, 300 to 400, and greater than 400.

In addition to the population distribution, parameters such as area-weighted drainage density, mean slope, and land-cover distribution, are also considered as major drivers for hydrologic, pollutant, and nutrient transport in catchments. To quantify these parameters and test their often assumed homogeneity between monitored and unmonitored drainage basins, we calculate for each of the seven marine areas of the Baltic Sea (see labels in Figure 2) quotients in area-weighted population, land cover, drainage density, and slope distribution between unmonitored and monitored drainage basins. All these quotients are denoted unmonitored/monitored for each parameter. The most important criterion for choosing input data for calculation of these parameters was transborder harmonization that would minimize the in-region variance caused by differing base-data quality. Therefore, land cover was calculated by use of Global Land Cover 2000 (23), drainage density by use of the Digital Chart of the World (24), and slope by use of HYDRO1k data (25).

RESULTS

The developed new spatial-hydrologic base map of the BSDB includes 634 catchments larger than 6 km^2 and is illustrated in Figure 1. In comparison with the drainage-basin delineation of the Baltic Sea Region GIS, Maps, and Statistical Database (9), the new map represents an increase in number and detail by approximately a factor of 5 to 10 (exemplified in Figure 4). Coding systems attached to the data facilitate aggregation to several relevant hydrologic scales. The whole BSDB covers an area of 2 150 000 km^2, of which 1 739 000 km^2 are on land and 410 000 km^2 are covered by the Baltic Sea itself. The total BSDB area measurement has only changed −0.3% compared with Sweitzer et al. (9), but delineation differences of individual catchments may be much larger. Boundaries, and thereby area and population estimates, of some major river basins are drastically changed, for example, in the Neva, Vistula, and Klarälven river basins. Drastic differences are also obtained for 553 relatively small catchments that were previously not even identified as separate catchments.

Table 1 lists population and area statistics and comparisons with Sweitzer et al (9) for drainage basins that correspond to the seven major marine areas of the Baltic Sea. These results show that a total of 84 239 000 people populated the BSDB in 2002, which results in a population density of 48 km^{-2}. Approximately 65% of the population lived in the Baltic Proper drainage basin and 15% lived in the Gulf of Finland drainage area. The Bothnian Bay drainage area has the lowest population and population density (5 persons km^{-2}) and accounts for only 1.5% of the total BSDB population. Population density was highest in the Danish Straits drainage area (190 persons km^{-2}). Comparison with the results of Sweitzer et al. (9) shows that the population distribution differs particularly for the Gulf of Riga (−13%) and the Kattegat (−16%) areas. The difference for Kattegat can be explained by the difference in drainage-basin area (−13%) that results from the present higher-precision delineation. The difference for the Gulf of Riga, however, is not caused by drainage-area difference, but can be explained by a general population decrease in the region, estimated for Estonia to be −14%, for Latvia to be −13%, for Lithuania to be −6%, and for Belarus to be −2% between 1990 and 2000 (34).

Table 2 lists area and population statistics for parts of countries within the BSDB. Among the results can be found that 26% of the BSDB area with 18% of the population is outside the EU and, thus, not bound by environmental legislation such as the EC Water Framework Directive. Furthermore, about 7.5% of the area with 8.5% of the population is found in countries without any Baltic Sea coastline of their own. Although population estimates compared with Sweitzer et al. (9) differ, especially for the Czech Republic (+13%), Germany (−7.5%), Estonia (−8%), and Latvia (−11%), the smaller relative changes in countries with a large share of total BSDB population, such as Poland (+2%), Russia (−4%), and Sweden (+4%), translate into greater absolute differences.

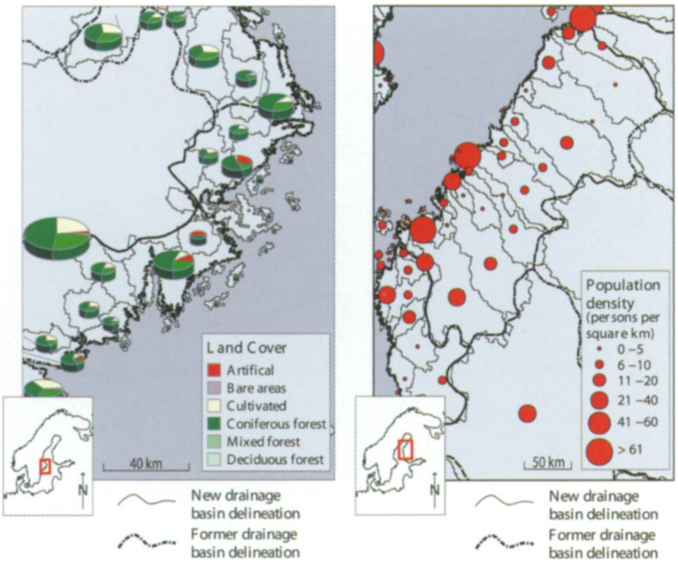

Figure 4. Exemplified spatial resolution of the former (thick lines) and the updated (thin lines) delineation of Baltic Sea drainage basins, along with the variability of basin characteristics over space in terms of (a) land-cover distribution in percent of area in the Stockholm region, with the size of charts determined by the associated drainage-basin area, and (b) population density of drainage basins in western Finland.

Table 3 lists area and population statistics for buffer zones of various distances from the Baltic Sea coastline. Results show that 19% of the population lives less than 10 km from the coast. This zone corresponds to 5% of the total BSDB area and yields coastal-population density of approximately 161 persons km^{-2}. Approximately 40% of the population lives within 100 km of the coast.

Figure 2 illustrates the distinction between monitored and unmonitored drainage areas in the whole BSDB, with regard to substance (nutrient) concentration monitoring only. Results show that these unmonitored areas cover 11% of the BSDB area but contain as much as 21% of the total BSDB population. Figure 3 illustrates that, for Sweden, the water-flow monitoring is often at different locations or even in different drainage basins than the nearest nutrient-concentration measurements. Calculations for Sweden show that 17% of its total area is not covered by nutrient-concentration monitoring and 16% is not covered by water-flow monitoring. These unmonitored areas contain 47% and 52% of the Swedish population, respectively. Areas without the combination of both water-flow and nutrient-concentration monitoring cover 20% of the total area of Sweden and 55% of its

Table 1. Population and area statistics of the drainage areas of the seven major marine areas of the Baltic Sea.

Name	Area (km^2)	Population	Share of total BSDB population (%)	Population density (km^{-2})	Area difference relative to Sweitzer et al. (9) (%)	Population difference relative to Sweitzer et al. (9) (%)
Baltic Proper	571 600	55 024 000	65	96	−0.5	+1
Bothnian Bay	263 500	1 323 000	1.5	5	−2	−5.5
Bothnian Sea	227 600	2 431 000	3	11	0	−5.5
Danish Straits	30 000	5 715 000	7	190	+1.5	+6
Gulf of Finland	428 000	12 618 000	15	30	+3	−0.5
Gulf of Riga	137 200	4 037 000	5	29	+1	−13
Kattegat	81 400	3 091 000	3.5	38	−13	−16
Entire BSDB	1 739 400	84 239 000	100	48	−0.5	−1

Table 2. Population and area statistics of parts of countries within the Baltic Sea Drainage Basin.

Country	Area (km^2)	Share of BSDB area (%)	Population	Share of BSDB population (%)	Population density (km^{-2})	Population compared to Sweitzer et al. (9) (%)
Belarus	88 500	5	3 801 000	2	43	−4
Czech Republic	9 500	0.5	1 745 000	2	184	+13
Denmark	27 300	1.5	4 469 000	5	163	0
Estonia	45 200	2.5	1 432 000	2	32	−8
Finland	302 600	17	5 142 000	6	17	+3
Germany	26 300	1.5	2 844 000	3	108	−8
Lithuania	64 600	4	3 600 000	4	56	−1.5
Latvia	64 200	4	2 359 000	3	37	−11
Norway	13 900	1	34 000	0	2	0
Poland	309 900	18	38 578 000	46	124	+2
Russia	330 000	19	9 700 000	12	29	−4
Sweden	439 800	25	8 795 000	10	20	+4
Ukraine	17 500	1.0	1 740 000	2	99	−1
Entire BSDB	1 739 400	100.0	84 239 000	100	48	−1

Table 3. Population and area statistics of buffer zones at different distances from the Baltic Sea Coast.

Distance from coastline (km)	Area (km^2)	Population	Share of total BSDB population (%)	Population density (km^{-2})
0–10	101 300	16 353 000	19	161
10–50	226 500	10 858 000	13	48
50–100	243 400	6 138 000	7	25
100–200	446 000	10 348 000	12	23
200–300	371 500	12 916 000	15	35
300–400	198 700	10 575 000	13	53
>400	152 000	17 050 000	20	112
Entire BSDB	1 739 400	84 239 000	100	48

population. If the same relation between monitored areas for nutrient concentrations and those for combined water-flow and nutrient-concentration monitoring is assumed for the whole BSDB as for Sweden, it implies that approximately 13% of the total BSDB area, which contains 24% of the total BSDB population, is not covered by relevant nutrient-pollutant mass-flow monitoring. The relatively large population share of unmonitored basins in the BSDB and, particularly, in Sweden, combined with the general close proximity of unmonitored areas to the coast (Figs. 2 and 3) indicates a possibly large unmonitored nutrient and pollutant loading to the Baltic Sea.

Figure 4 shows the variation of population density and land-cover distribution for some unmonitored coastal catchments in Finland and Sweden. The unmonitored basin characterization shows that these areas are characterized by large variability in the studied parameters: population, land cover, drainage density, and slope. Such variability has not previously been reported or accounted for by BSDB-wide modeling approaches.

Figure 5 summarizes a quantitative comparison of monitored and unmonitored drainage-basin characteristics, in terms of resulting quotients (unmonitored/monitored) for area-weighted mean values of the considered characterization variables in all drainage basins that drain into each of the seven marine areas. Results show that the characteristics of unmonitored areas deviate largely from those of the monitored areas. Out of 11 investigated parameters and 7 marine areas that yielded 77 different quotients, only 20 (26%) of the comparative quotients are within the range 0.8 to 1.2 (±20%), and 15 (19%) are either larger than a factor 4 (+300%) or smaller than a factor ¼ (−75%). Population density and distribution of artificial surfaces are the parameters that differ the most, with quotients in the range 0.8 to 12.1 (−20% to +1110%) and 1.2 to 13.9 (+20% to +1290%), respectively, and with only one representation in the ±20% band. For individual drainage basins, parameter characteristics will naturally differ even more than for the chosen marine-area aggregation of basins. In general, results show that population density and abundance of artificial and cultivated land are higher in unmonitored than in the monitored drainage basins, whereas herbaceous land, lichens, and mosses are less abundant and the drainage density and slope is lower in the former.

CONCLUSIONS

Nutrient loading to the Baltic Sea has been difficult to predict and abate, with surprisingly long delays between changes of important drivers and responses of nutrient loading in streams (35). Recently noted model-resolution issues and gaps in hydrologic-pollutant load and process recognition (36–38) may partly explain such difficulties, with characterization results presented in this paper, for drainage-basin areas of different monitoring and characterization resolution, also pointing in similar direction. The present results indicate that a large number of relatively small but densely populated coastal-drainage basins are systematically unmonitored with regard to their nutrient-pollutant loading to the sea. Site-specific calibration and validation of hydrologic-pollutant and nutrient-transport models are then impossible for these unmonitored areas. Instead, the same characteristics as for adjacent monitored basins are extrapolated to the unmonitored coastal basins and, thus, assumes hydrologic and pollutant-transport homogeneity. Present results show that drainage-basin characteristics may be highly variable among and between unmonitored and monitored basins. In particular, the found systematic population-density differences between unmonitored and monitored basins may imply considerable unquantified and, thus, unabated pollutant and nutrient loading from inland waters to the Baltic Sea. Our more detailed analysis of Swedish catchments indicates Sweden as having a particularly large proportion of unmonitored coastal catchment areas (20% of the total Swedish area) with high population pressures (55% of the total Swedish population),

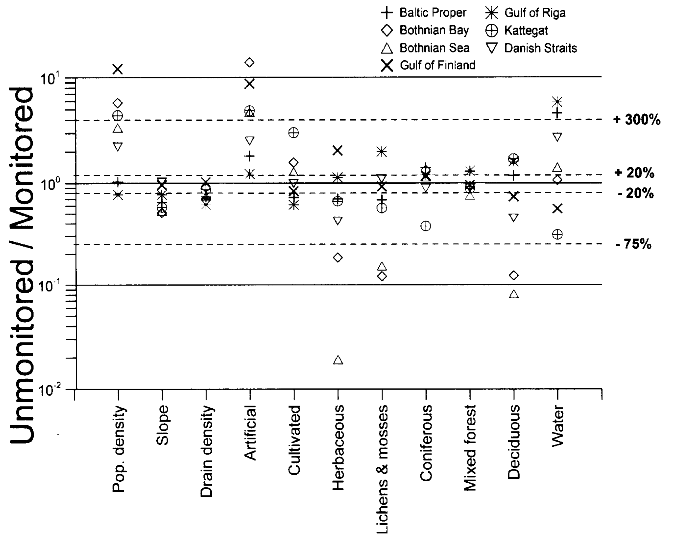

Figure 5. Comparative quotients (unmonitored/monitored) of area-weighted mean values of a range of different basin-characterization variables (population, drainage density, slope, and eight land-cover classes) in unmonitored relative to monitored drainage basins of each of the seven marine areas defined in Figure 2.

when compared with average conditions for the whole BSDB. In general, the investigated characteristics of unmonitored coastal basins vary and differ largely from those in adjacent monitored drainage basins within the BSDB.

In general, the variable hydrologic characteristics and common high population pressure of coastal areas imply a need for increased focus on unmonitored coastal basins in forthcoming monitoring and modeling efforts, to capture the relevant spatial distribution and dynamics of pollutant and nutrient loading to coastal waters. Other studies indicate that spatially resolved catchment and nutrient-pollutant source characterization may be essential for supporting relevant, effective, and efficient abatement of nutrient loading from land to sea (37, 38). The new database presented in this paper represents a step toward better geographically distributed characterization of the catchments and nutrient-pollutant sources of the BSDB.

DATA DISTRIBUTION

The presented drainage-basin delineation and characterization data for all 634 drainage basins are freely available in a standard GIS format, together with descriptive metadata, at http://www.geo.su.se/Hydrology.

References and Notes

1. Graham, P. 1999. Modeling runoff to the Baltic Sea. *Ambio 28*, 328–334.
2. Jansson, Å., Folke, C., Rockström, J. and Gordon, L. 1999. Linking freshwater flows and ecosystem services appropriated by people: the case of the Baltic Sea drainage basin. *Ecosystems 2*, 351–366.
3. Turner, R.K., Georgiou, S., Gren, I.-M., Wulff, F., Barrett, S., Söderqvist, T., Bateman, I.J., Folke, C., et al. 1999. Managing nutrient fluxes and pollution in the Baltic: an interdisciplinary simulation study. *Ecol. Econ. 30*, 333–352.
4. Stålnacke, P., Grimvall, A., Sundblad, K. and Tonderski, A. 1999. Estimation of riverine loads of nitrogen and phosphorus to the Baltic Sea, 1970–1993. *Environ. Monit. Assess. 58*, 173–200.
5. European Parliament and the Council of the European Union. 2000. Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000, establishing a framework for community action in the field of water policy. *Off. J. Eur. Communities L. 327*, 1–73.
6. Nilsson, S., Langaas, S. and Hannerz, F. 2004. International river basin districts under the EU Water Framework Directive: identification and planned cooperation. *Eur. Water Manag. Online 2004*, 1–20.
7. Langaas, S. (ed.). 1992. *Regional Environmental GIS Data Sets of the Nordic Countries and the Baltic Sea Drainage Basin: A Documentation. GRID-Arendal Report Series No. 1*, 29 pp.
8. Turner, R.K., Mäler, K.G., Pethig, R., Wulff, F., Langaas, S., Johansson, P-O., Krysanova, V., Vitkovskis, R., et al. 1995. *The Baltic Drainage Basin Project* (EV5V-CT-92-0183): Summary. Final Report. European Commission, Brussels, 6 pp.
9. Sweitzer, J., Langaas, S. and Folke, C. 1996. Land cover and population density in the Baltic Sea Drainage Basin: a GIS database. *Ambio 25*, 191–198.
10. Langaas, S. 1998. Transboundary European GIS databases: A review of the Baltic region experiences. In: *European Geographic Infrastructures. Opportunities and Pitfalls.* Burrough, P. and Masser, I. (eds.). Taylor & Francis, London, pp. 31–44.
11. Malmberg, U. 2001. *BALANS Land Cover and Land Use Classification Methodology.* Metria Miljoanalys, Stockholm, 83 pp.
12. Ursin, H. 2001. *MapBSR, Digital Map of the Baltic Sea Region.* Paper presented at the 7th EC-GI & GIS Workshop, EGII - Managing the Mosaic, Potsdam, Germany, June 13–15, 2001.
13. Baltic Sea Region GIS, Maps and Statistical Database. (http://www.grida.no/baltic)
14. Information extracted from a voluntary on-line survey hosted by UNEP/GRID-Arendal given at data download.
15. HELCOM. 1986. *Water Balance of the Baltic Sea.* Environment Proceedings No. 16. The Helsinki Commission, Finland, 174 pp.
16. Department of Systems Ecology, Stockholm University 2005. Baltic Environmental Database. (http://data.ecology.su.se/models/bed.htm)
17. EEA 2005. Waterbase—Rivers. (http://dataservice.eea.eu.int/dataservice)
18. Smith, S.V., Swaney, D.P., Buddemeier, R.W., Scarsbrook, M.R., Weatherhead, M.A., Humborg, C., Eriksson, H. and Hannerz, F. 2005. River nutrient loads and catchment size. *Biogeochemistry 75*, 83–107.
19. Hiederer, R. and de Roo, A. 2003. *A European Flow Network and Catchment Data Set.* EUR 20703 EN, European Commission Joint Research Centre, Ispra, Italy.
20. HELCOM 2003. Manual for Marine Monitoring in the COMBINE Programme of HELCOM. (http://www.helcom.fi/combine_manual/contents.html)
21. Hannerz, F. 2002. *Harmonisation and Applications of Transboundary Geographic Databases of the Baltic Sea Region: Drainage Basin Characterisation.* Masters Thesis, Royal Institute of Technology, Stockholm, Sweden.
22. Oak Ridge National Laboratory. 2004. *LandScan 2002 Global Population Database.* Oak Ridge National Laboratory, Oak Ridge, Tennessee.
23. Joint Research Centre. 2003. *Global Landcover Classification 2000.* EC Joint Research Centre, Ispra.
24. Defense Mapping Agency. 1992. *Digital Chart of the World.* Defense Mapping Agency, Fairfax, Virginia.
25. U.S. Geological Survey. 1998. *HYDRO1k.* Earth Resource Observation System Data Center, Sioux Falls, South Dakota.
26. Vogt, J.V., Colombo, R. and Bertolo, F. 2003. Deriving drainage networks and catchment boundaries: a new methodology combining digital elevation data and environmental characteristics. *Geomorphology 53*, 281–298.
27. European Commission. DG Environment Reporting Archives, Brussels, July 2004.
28. Humborg, C., Danielsson, Å., Sjöberg, B. and Green, M. 2003. Nutrient land-sea fluxes in oligothrophic and pristine estuaries of the Gulf of Bothnia, Baltic Sea. *Estuar. Coast. Shelf Sci. 56*, 781–793.
29. USGS. 2005. Seamless Data Distribution. (http://seamless.usgs.gov)
30. Euro maps, 1996. Dataset. Bartholomew, Dublin.
31. SMHI 2005. Vattenstånd/Vattenföring. (http://www.smhi.se)
32. Dobson, J.E., Bright, E.A., Coleman, P.R., Durfee, R.C. and Worley, B.A. 2000. LandScan: a global population database for estimating populations at risk. *Photogramm. Eng. Rem. Sens. 66*, 849–857.
33. Sutton, P. 1997. Modeling population density with night-time satellite imagery and GIS. *Com. Environ. Urban Syst. 21*, 227–244.
34. United Nations 2002. World Population Prospects: The 2002 Revision and World Urbanization Prospects. (http://esa.un.org/unpp)
35. Stålnacke, P., Grimvall, A., Libiseller, C., Laznik, M. and Kokorite, I. 2003. Trends in nutrient concentrations in Latvian rivers and the response to the dramatic change in agriculture. *J. Hydrol. 283*, 184–205.
36. Lindgren, G. and Destouni, G. 2004. Nitrogen loss rates in streams: scale dependence and up-scaling methodology. *Geophys. Res. Lett. 31*, L13501, doi:10.1029/2004GL019996.
37. Darracq, A. and Destouni, G. 2005. In-stream nitrogen attenuation: model artifacts and management implications for coastal nitrogen impacts. *Environ. Sci. Technol. 39*, 3716–3722.
38. Baresel, C. and Destouni, G. 2005. Novel quantification of coupled natural and cross-sectoral water and nutrient/pollutant flows for environmental management. *Environ. Sci. Technol. 39*, 6182–6190.

39. We thank the Swedish Research Council for financial support. We thank H. Eriksson, C. Humborg, M. Mörth, M. Rodriguez-Medina, E. Smedberg, and F. Wulff, Stockholm University, for their guidance on and explanation of general needs and uses of spatial data, relevant classification of land-cover categories (especially E. Smedberg), and handling of monitored and unmonitored catchments within the main current Baltic Sea research projects "European Lifestyles and Marine Ecosystems" (ELME, an EU 6th FP project) and "Marine Research on Eutrophication" (MARE, Swedish MISTRA project) and the Baltic Environmental Database. We thank S. Langaas, the Royal Institute of Technology (KTH), for making download statistics from the Baltic Sea Region GIS, Maps and Statistical Database available to us and S. Nilsson, KTH, for sharing spatial boundaries of Water Framework Directive Districts.

Fredrik Hannerz is a PhD student at the Department of Physical Geography and Quaternary Geology at Stockholm University. His thesis deals with the role and application of spatial hydrologic information systems for water management. His address: Department of Physical Geography & Quaternary Geology, Stockholm University, SE-106 91 Stockholm, Sweden.
fredrik.hannerz@natgeo.su.se

Georgia Destouni is a professor of hydrology, hydrogeology and water resources at the Department of Physical Geography and Quaternary Geology, Stockholm University. Her main research interests include hydrological transport of solute, nutrients and pollutants, groundwater-surface water and freshwater-seawater interactions. Her address: Department of Physical Geography & Quaternary Geology, Stockholm University, SE-106 91 Stockholm, Sweden.
Georgia.Destouni@natgeo.su.se