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The influence of land cover change during sixty years on non point source phosphorus loads to Gulf of Gdansk

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ABSTRACT

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The main source of phosphorus in coastal waters is the load from land. Land cover change in time may in significant way increase or decrease the amount of phosphorus runoff. The aim of the study was to compare the land cover of a part of the Gulf of Gdansk catchment in 1940 and 2000 and analyze the resulting change in the annual diffuse phosphorus loads to coastal waters of Baltic Sea. For the evaluation of the land use change, Messtischblatt maps from year 1940 and Corine Land Cover 2000 were used. For the estimation of annual total phosphorus loads from the analyzed area, export coefficients expressed as kg P ha^{-1} $year^{-1}$, defined for Corine Land Cover classes were used. The land cover characteristic of the investigated area changed significantly in the analyzed sixty years period. The most visible change was caused by urbanization as the area of urban fabric land cover class increased from 12% to 29% of the area. The agricultural and semi natural lands, changed mostly in the urban type, decreased by 6% and 9% respectively. These transformations resulted in the increase of non point source phosphorus load from analyzed area by 20% and changes in contribution of loads from particular land cover classes.

ADDITIONAL INDEX WORDS: *annual phosphorus loads, land cover change, export coefficient*

INTRODUCTION

The main source of phosphorus in coastal waters is the load from land with the process of non point source runoff as an important part. The excess of phosphorus in natural waters may result in some ecological problems and disturb the balance of organisms present in reservoir. The eutrofication of water basin, a serious problem of many coastal waters leading to many ecological consequences, depends on the phosphorus input from the catchment to the receiver. Land cover change, with transformation of natural to urban, impervious areas causes increased runoff of wide range of pollutants including nutrients, pesticides, sediment and heavy metals enhancing deterioration of quality of water (Bhaduri, 2000).

The aim of the study was to compare the land cover of a part of the Gulf of Gdansk catchment in 1940 and 2000 and analyze the resulting change in the annual diffuse phosphorus loads to coastal waters of Baltic Sea. The total catchment area of Gulf of Gdańsk covers more than 50 % of the area of Poland, as the biggest river, Vistula with catchment about 200 000 km^2 flows into. Without taking Vistula into consideration the catchment of Gulf of Gdansk is approximately 2700 km^2 (Rybiński, 1994), the analyzed 270 km^2 area (see Figure 1) including the Gdansk – Sopot – Gdynia agglomeration, covers the most intensively used urban area and the analyzed 60 year period included extensive human impact after the Second World War. The annual phosphorus loads were estimated on the basis of export coefficients from the particular land cover type. The export coefficient modelling enables to predict the total annual nutrient loading as a sum of export of nutrients from each source in the analyzed catchment (Johnes, 1996). The export coefficients defined for different land use classes describe the annual average amount of phosphorus in kg that is supplied from an area unit (ha) of particular type of land cover. This method provides inexpensive tool for estimating average annual non point source phosphorus loads from analyzed area (McGuckin et al., 1999).

DATA AND METHODS

Data preparation

For the evaluation of the land use change, maps of land cover from years 1940 and 2000 were used. The Corine Land Cover (CLC) map, published by European Environment Agency, was produced from the Landsat satellite images and corresponds to the scale of 1:100 000. The map of the land cover in 1940 was prepared from the analog German topographic maps of the Messtischblatt series, 1: 25 000 scale. There was a problem with identifying zones of originally used projection of Messtischblatt maps, as Das Deutsches Hauptdreiecksnetz no longer include zones of analyzed area due to territorial change after the Second World War. For proper registration the Das Deutsches Hauptdreiecksnetz projection was modified and the central

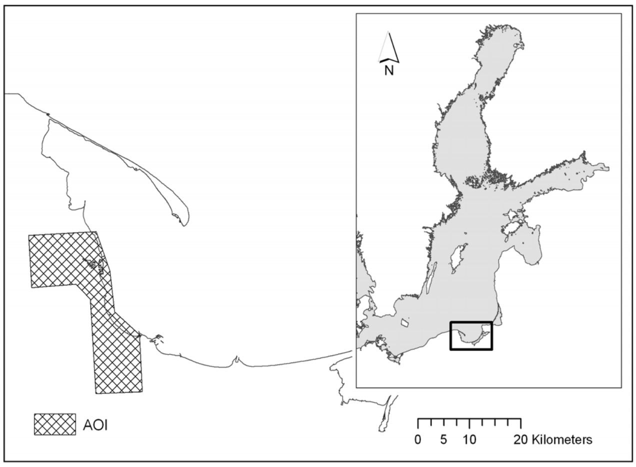

Figure 1. Location of the analyzed area – part of a catchment of Gulf of Gdansk, Baltic Sea.

meridian was changed to 18 E. After this modification the georeferencing of scanned maps was achieved.

The next stage in preparing the land cover maps for the year 1940 was the on screen digitization of areas of particular land cover types to polygons. The adjustments of land cover classes of Corine and land cover indicated on Messtischblatt maps was needed for comparative analysis. The CLC classes of *continuous urban cover* and *discontinuous urban fabric* was combined into one class and named *urban fabric*.

After digitizing all the land cover classes indicated on the legend of Messtischblatt maps, there still were areas where land cover type could not be identified (Fig. 2). In such situation the CLC 2000 maps were used to estimate the most probable land cover. In unidentified areas overlying with the CLC 2000 classes not indicated in 1940 maps: non-irrigated arable land, good pasture and complex cultivation patterns, those CLC2000 classes were assigned. This procedure, however, was not possible for example in urban and forest CLC2000 areas as in Messtischblatt maps those classes were marked. From the historical knowledge, as established by the authors, these areas were mainly characterized by the grasslands with some impact of human activity. On this basis, regions surrounding urban regions were assigned to the green urban areas class and for remaining regions, closer to forest and agricultural areas, new class was created: *land principally occupied by agriculture with significant areas of natural vegetation including grassland*. As a result the map of land cover for 1940 year included whole area of analysis and the estimation of phosphorus loads in 1940 to coastal waters could be conducted.

Export coefficient modelling

For the estimation of annual total phosphorus loads from the analyzed area, export coefficients expressed as kg P $ha^{-1}year^{-1}$, defined for Corine Land Cover classes were used. The phosphorous export coefficients for land cover classes present in the area of interests were selected from the values presented in the literature: McGuckin (2000), PLUARG (1978) and Ferrier et al. (1996). For the newly introduced class (land principally occupied by agriculture with significant areas of natural vegetation including grassland) the export coefficient of phosphorous loads was calculated as the mean value of export coefficients of 2 known classes: *natural grassland* and *land principally occupied by agriculture with significant areas of natural vegetation*. Combining of *continuous urban cover* and *discontinuous urban fabric* had no influence in the results of annual phosphorus input estimation, as the export coefficients were equal for both of these classes. As there was no export coefficient found for construction sites, for this class the export coefficient of *industrial or commercial units* was adopted. The export coefficients for land cover classes that appear on the 1940 or 2000 map are grouped in the table 1.

For each existing land cover class the total phosphorus load was determined by multiplying the total land area of particular class by its export coefficient. This approach was conducted for the maps from 1940 and 2000 year. To obtain total annual phosphorus input the individual land cover classes loads were summed. This gives the estimation of the total phosphorus from non-point sources loads in particular year.

RESULTS AND DISCUSSION

The land cover characteristic changed significantly in the analyzed sixty years period. In 1940 the analyzed area was mainly occupied by mixed forests, lands of semi-agricultural, semi-natural

Table 1. The export coefficient for the land cover classes present on the analysed maps.

LCL Class	CLC Class Level 3	Export Coefficient kg P ha^{-1} $year^{-1}$
111	Continuous urban cover	1.2
121	Industrial or commercial units	2.5
122	Road and rail networks and associated land	1.2
123	Seaports	2.5
124	Airports	2.5
133	Construction sites	2.5
141	Green urban areas	0.83
142	Sport and leisure facilities	1.2
211	Non-irrigated arable land	4.88
231	Good pasture	0.83
242	Complex cultivation patterns	2.33
243	Land principally occupied by agriculture with significant areas of natural vegetation	0.49
300	Land principally occupied by agriculture with significant areas of natural vegetation including grassland	0.55
311	Broadleaved forest	0.26
312	Coniferous forest	0.36
313	Mixed forest	0.26
321	Natural grassland	0.62
322	Moor and heathlands	0.13
324	Transitional woodland/scrub	0.26
331	Beaches, dunes, and sand plains	0
411	Inland marshes	0.23
412	Peat bogs	0.23
511	Water bodies	0.5

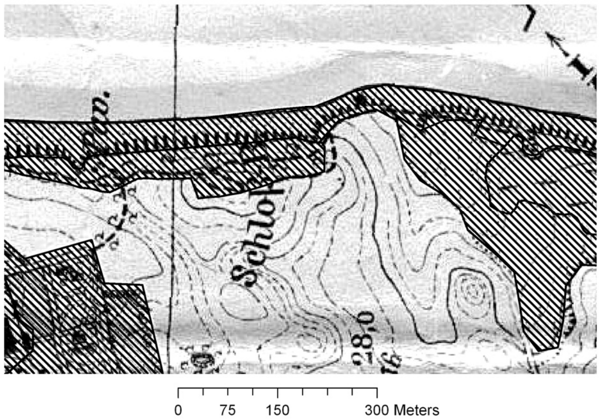

Figure 2. A part of Messtischblatt map with digitized land cover polygons (marked with black lines) and area with no indication of land cover.

characterization and urban areas covered about 12% of the area. Sixty years later the *urban fabric* land cover class dominated with almost 29% of the area, the natural grasslands and grasslands with agricultural impact disappeared. The area of forests increased by 20 % in analyzed period and the composition of forests also changed. The area of broadleaf forests spread significantly, while the coniferous and mixed forests reduced (Tab. 2). The differences in the extend between 1940 and 2000 for urban fabric, heterogeneous agricultural areas (including *complex cultivation patterns, land principally occupied by agriculture with significant areas of natural vegetation* and *agricultural areas combined with grassland*), and forests and semi-natural areas are presented on the maps on the figure 3. The main cities in the analyzed area spread significantly from 1940, while agricultural and natural lands shrank.

These changes in land cover characteristics had influence on the annual phosphorus input from this catchment area to Gulf of Gdansk. The amount of phosphorus load per year increased from 30 tonnes in 1940 to 37 tonnes in 2000. The contribution of total phosphorus load from different classes changed, as a result of the change in the contribution of total area of those classes. Part of semi natural and agricultural areas were transformed into urban fabric, so the phosphorus input from these types of land cover decreased while the phosphorus input from artificial land cover types doubled (Fig. 4).

In the analysis of long term hydrologic impacts of land use change performed by Bhaduri et al. (2000) the 19 % change from non-urban to urban land cover introduced the 12,5 % decrease of phosphorus in annual average runoff. In that case the change was between 1974 to 1991 and this reduction resulted from lowering

Table 2. Contribution of land cover categories to total area and total phosphorus loads in years 1940 and 2000.

CORINE Land Cover Class		% of total (273km2) analyzed area		Contribution to Total Phosphorus 1940		Contribution to Total Phosphorus 2000	
		1940	2000	kg P year^{-1}	%	kg P year^{-1}	%
211	Non-irrigated arable land	9.69	10.82	12884	42.58	14412	38.91
231	Good pasture	0.85	2.14	192	0.63	485	1.31
242	Complex cultivation patterns	4.51	3.86	2864	9.46	2455	6.63
243	Land principally occupied by agriculture with significant areas of natural vegetation	0.63	1.89	84	0.28	253	0.68
300	Land principally occupied by agriculture with significant areas of natural vegetation including grassland	19.20	0.00	2875	9.50	0	0.00
111	Continuous urban cover	12.24	28.65	3999	13.22	9379	25.32
122	Road and rail networks and associated land	0.28	0.77	92	0.30	253	0.68
123	Seaports	3.04	2.22	2069	6.84	1516	4.09
141	Green urban areas	6.88	4.21	1556	5.14	952	2.57
311	Broadleaved forest	2.35	15.86	166	0.55	1125	3.04
312	Coniferous forest	3.20	1.19	314	1.04	116	0.31
313	Mixed forest	25.16	19.71	1782	5.89	1398	3.77
321	Natural grassland	6.01	0.00	1015	3.35	0	0.00
322	Moor and heathlands	1.80	0.00	64	0.21	0	0.00
324	Transitional woodland/scrub	0.95	0.00	67	0.22	0	0.00
511	Water bodies	0.68	0.46	93	0.31	63	0.17
412	Peat bogs	2.25	0.00	141	0.47	0	0.00
331	Sands, dunes	0.28	0.30	0	0.00	0	0.00
121	Industrial or commercial units	0.00	4.19	0	0.00	2855	7.71
124	Airports	0.00	1.27	0	0.00	865	2.34
133	Construction sites	0.00	0.42	0	0.00	288	0.78
142	Sport and leisure facilities	0.00	1.89	0	0.00	619	1.67
411	Inland marshes	0.00	0.15	0	0.00	9	0.03

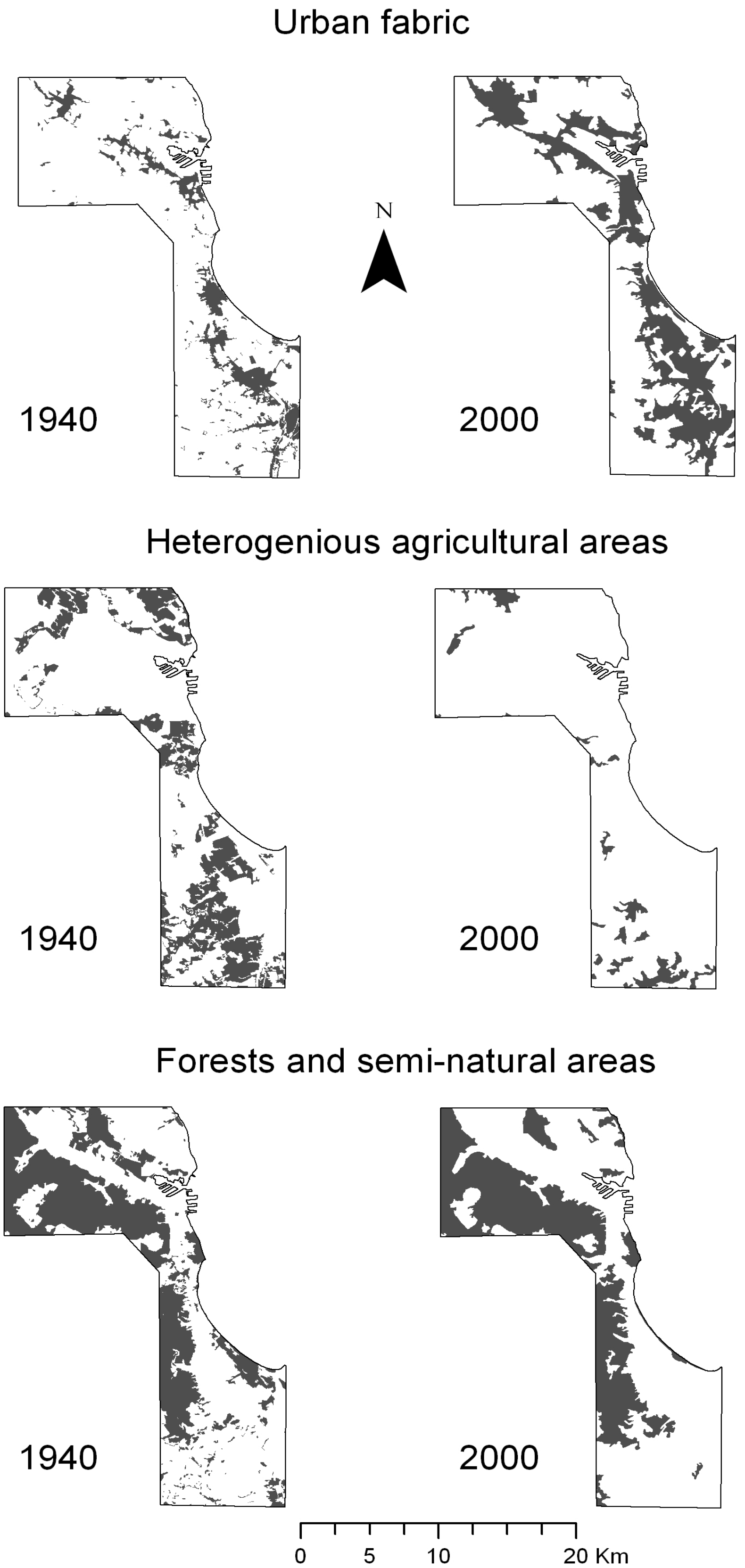

Figure 3. Maps of the extend of land cover categories in years 1940 and 2000.

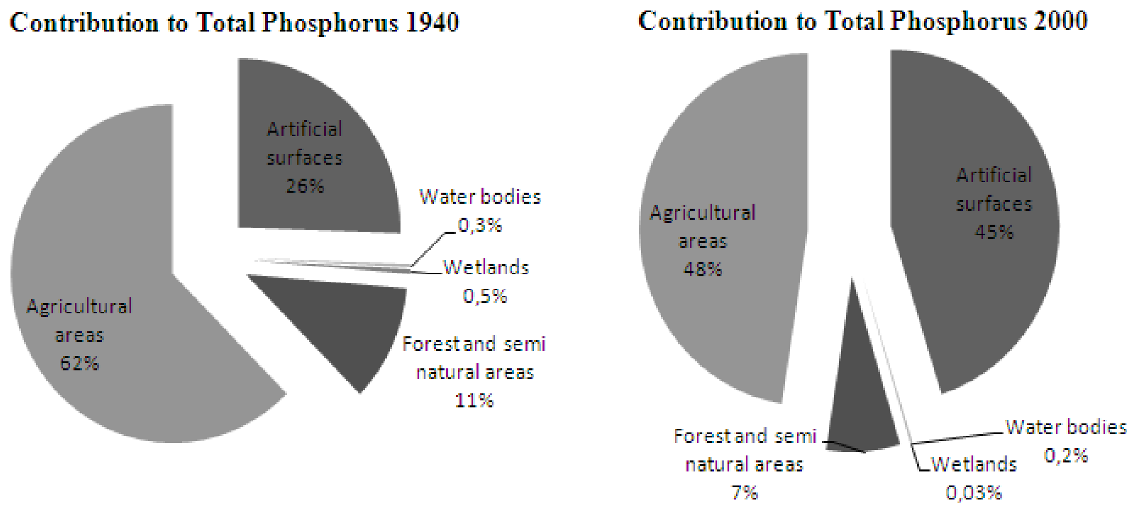

Figure 4. Contribution of Corine Level 1 land cover categories to estimated annual total phosphorus load for year 1940 and 2000.

the extend of agricultural areas introducing higher amounts of P than urban. In the present analysis the land cover change resulted in the reduction of semi-natural and natural areas having low values of export coefficients for the benefit of urban fabric characterized by higher losses of phosphorus and led to the higher annual phosphorus input to coastal waters.

The method used for estimating annual phosphorus load using export coefficient is simple from the point of methodology, nevertheless, requires proper rates of export coefficient for particular land cover classes. The usage of the same values for analysis amounts of total phosphorus in 1940 and 2000 introduces inaccuracy of results in 1940, however, predictions of real values of phosphorus input from land types at that time would require much more information. In this study the influence of land use change on phosphorous input is analyzed and this approximation seems to be sufficient. The results would be more adequate if the land cover in 1940 was defined more precisely for example by the old aerial photographs, as on wide areas there was no information about land cover on maps and it had to be approximated with the information of present data.

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