THE IMPACT OF ANTHROPOGENIC PRESSURE ON THE CHANGE OF WATER RELATIONS IN GARDNO-ŁEBA LOWLAND

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ABSTRACT: This article presents an analysis of cartographic materials of the 19th and 20th centuries in terms of changes in the surface water network of the Gardno-Łeba Lowland. The obtained results confirmed that the natural water network was slightly transformed in the first half of the 19th century and considerably increased in the 20th century as a result of agricultural drainage system, especially drainage of wetlands, and river regulations. As a consequence, a hydrographic system with a forced water circulation has developed, that is quite different from the natural. On the one hand, it has become the reason for reversing the proportion in which the groundwater resources have been depleted, along with an increase in the surface water network density, and on the other hand it has caused a change in land use.

KEYWORDS: water relations, agriculture, irrigation, topographic map, land use

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Introduction

The Gardno-Łeba Lowland reveals a number of unique geographical features. This is due to its location in the coastal zone of the southern Baltic (Pomeranian region), which makes the water conditions of the lowland particularly interesting. The area of the lowland has an altitude of only 0 to 5 m and is characterized by the abundance of various hydrographic objects, among others: coastal lakes, rivers, streams, wetlands. Their existence is the result of the geological past and origin of alluvial plain formation and it results from the contemporary phenomena taking place here, remaining in close connection with the fluctuations in the main drainage base (the Baltic Sea level) and finally from an extensive land base represented by the Łupawa and Łeba river basins. Therefore, the lowland constitutes the direct contact area of waters from three aquatic environments: marine, terrestrial (freshwater) and atmospheric, different in terms of their characteristics and dynamic conditions.

In the late 18th century, the area of the Gardno-Łeba Lowland (Fig. 1) became valuable to people. Measures were taken to adapt the lowland to the changing needs of economy, by introducing agricultural irrigation. Consequently, the image of the lowland's original hydrographic system has been completely transformed. In addition to natural ones, artificial water bodies, resulting from anthropogenic activities (ponds, canals, irrigation ditches), are found on the lowland nowadays. Separately, the natural and artificial objects perform different hydrological functions, but as a whole, they make up the hydrographic

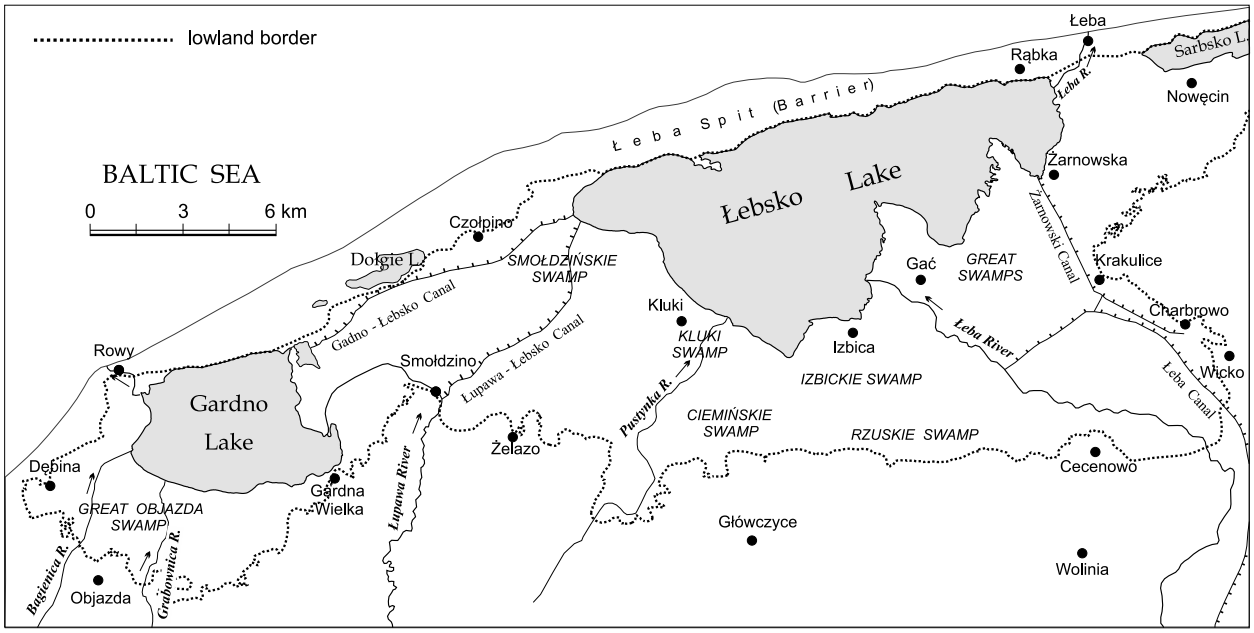

Fig. 1. The study area.

system remaining in mutual hydraulic relations, with a complex manner of water circulation.

Aim and methods

The main aim of the study is focused on a chronological reconstruction of changes in the water conditions in the Gardno-Łeba Lowland over the past 200 years and their tendencies, as well as on capturing the consequences, both in the hydrosphere and the land use. The basis for the reconstruction was the content of the detailed topographic maps of a 1:25,000 scale of three time periods: 1836–1837 (Urmesstischblätter), 1928–1936 (Meßtischblatt) and 1976–1986 (military maps). The water layer was dissected from these maps and then mutually compared. For this purpose, using the GIS software, the cartographic information was transformed to the reference map datum (Jankowska 1995), presented on the modern military topographic maps. The error of map adjustment was calculated. The average error range in relation to reference maps, was ± 13 m for the oldest maps and ± 5 m, for Meßtischblatt maps (Chlost 2010).

In some cases, cartometric calculations were made, and the results were presented graphically or in tables. The information obtained from the maps was complemented by data from the literature (Dreyer 1913, Cronau 1929, Malotki 1932, Szopowski 1962, Stelmachowska 1963, Lindmajer 1981, Szalewska 1984). Whereas, the current state of water relations was verified on the basis of hydrographic field survey. The presented course of action made it possible to establish the cause-effect relationships, and to assess the rate and direction of the changes in water relations of the Gardno-Łeba Lowland.

Changes in the hydrographic system

The reason for the changes in the original hydrographic system of the Gardno-Łeba Lowland, was the need to acquire new land for agricultural purposes and the introduction of effective protection against flood events affecting the local population. The first significant irrigation works in the area were carried out already in the late 18th century, and their general designer and executor was Franz von Brenkenhoff, who held the office of Secret Financial Counsellor and engineer at the court of the Prussian king Frederick the Great. Under his supervision, the water relations of Smołdzińskie swamps, located between Lake Łebsko and Gardno were regulated (1777), and the peat bogs in the Łeba glacial valley from Lębork to Łeba were drained. Canals and ditches of general and detailed land irrigation were created at that time (Fig. 2). The framework of the system which drained Smołdzińskie swamps, con-

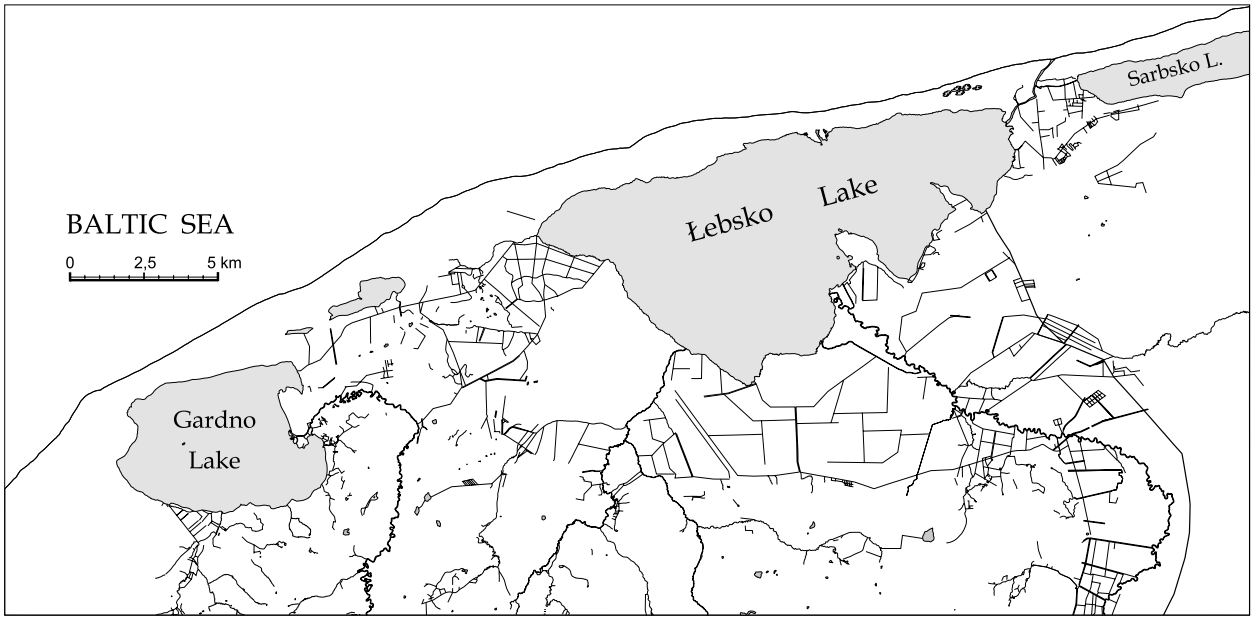

Fig. 2. Hydrographic network of Gardno-Łeba Lowland in the early 19th c.

sisted of two canals: one draining water towards both lakes Łebsko and Gardno (Gardno-Łebsko canal) and the canal connecting the river Łupawa to lake Łebsko (Łupawa-Łebsko canal). In the Łeba river glacial valley, the canal named after its constructor (Brenkenhoffkanal) of a length of 25 km, running from Chocielewko to lake Łebsko (now Łebski and Żarnowski canal), was constructed. The task of this canal was a partial capture and disposal of summer flood waters of the Łeba river and drainage of a high peat bog in its valley. Detailed drainage ditches accompanied mainly all the spot peat mining areas, scattered across the whole area of the Lowland, or those prepared for peat mining, as well as areas dedicated to pastures and meadows (mainly in the Łeba valley). The result of v. Brenkenhoff's activity in the Gardno-Łeba Lowland was reflected in the cartographic record of 1836–1837 (Chlost 2010). The lower sections of major rivers and other smaller streams were not yet regulated, which is demonstrated by their winding, meandering courses.

Although the human activity in the aquatic environment was significant even then, it did not contribute to serious consequences changing the hydrographic system in that time. It is evidenced by the record of wetlands stretching along the Łeba river glacial valley and further to the west, across the Rzuskie, Ciemińskie and Izbickie swamps. Wetlands accompanied the coastal lakes and surrounded them (except the north side), filled the valleys of smaller and larger rivers, streams and spring areas. Almost the entire lowland was marshy, with the exception of the Łeba Spit belt, inland dunes and moraine hummocks (Fig. 3).

After the death of v. Brenkenhoff and Frederick II, water engineering projects throughout Pomerania came to a standstill for nearly 100 years. The few works in this area were limited to maintenance of the existing facilities (Dreyer, 1913). It was only the establishment of "Law on Private rivers" (Privatflussgesetz) in 1843 and the "Law on Water Companies" in 1879 that brought further development of irrigation (Cronau 1929). A detailed analysis of cartographic material from the first half of the 20th century revealed the preferences for sites to be drained (Fig. 4). First of all, the courses of the two largest rivers were shortened and straightened, cutting off numerous meanders.

The Łupawa was regulated on a short distance from Smołdzino to the lake Gardno. An analysis of archival materials shows that the regulation of the river Łeba from Lębork to the lake Łebsko started a year before the outbreak of the World War I and was completed at the end of 1918. The river outlet into the lake was artificially modified. Originally, the river flowed into the lake just above the village Gać, and as a result of regulations, a new estuary was dug south of the old

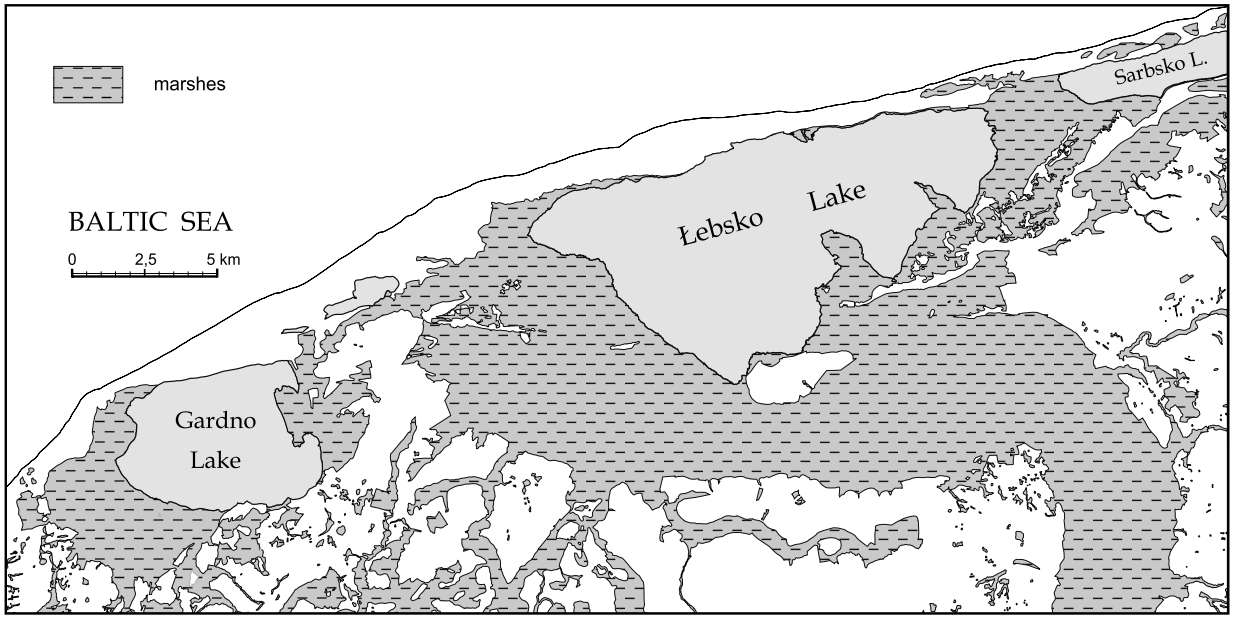

Fig. 3. Extent of wetlands in Gardno-Łeba Lowland in the early 19th c.

one. The analyzed maps also revealed the shape of the new Łeba estuary to the sea, which was stabilized and strengthened by breakwaters protruding into the sea in the years 1884–1889. The new bed was designed approximately 400 meters west of the one existing at that time, which reduced the river course in the section from the lake to the sea by 350 meters (Szopowski 1962, Kobendzina 1976).

In certain sections some of the smaller streams as the Pustynka, Główczycki Stream or Grabowa were also regulated, while the course of the Bagienica and Grabownica flowing into the lake Gardno, was still characterized by a natural meandering type of development.

At the turn of the 19th and 20th centuries, a very intensive drainage system works took place. They concerned the beds of both the main waterways' valleys and smaller river valleys, particularly those subject to regulation. Large areas of wetlands located to the south-west of lake Gardno (The Great Objazda Swamp), as well as

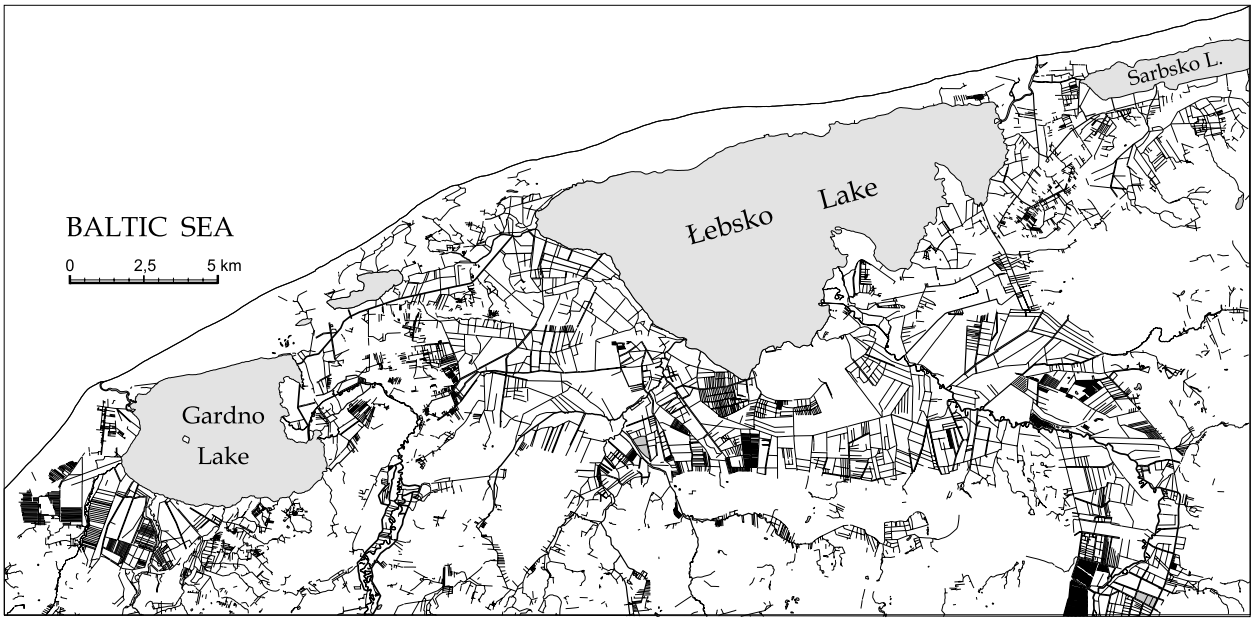

Fig. 4. Hydrographic network in the Gardno-Łeba Lowland in the early 20th c.

around the lake Łebsko, were drained. These were the wetlands of Smołdzińskie Swamp – west of the lake; Kluki Swamp – south-west; Ciemińskie, Izbickie and Rzuskie – south and the Wielkie Bagna (The Great Swamps) – south-east. The drainage system was also introduced between the lakes Gardno and Łebsko, and between the lakes Łebsko and Sarbsko, as well as the Łeba Spit area. Drainage ditches were made in the section from the lake Dołgie Wielkie to the lake Łebsko and around Rąbka, whilst leaving the wetlands located north of the settlement. The parts of the Łeba valley at the village Wolinia and Ciemińskie Swamp were drained most intensively. In both cases, the density of water network exceeded 20 km km^{-2}. The irrigation works were accompanied by the construction of associated facilities, such as embankments, dikes, mills with flood relief channels and drainage mechanisms, such as wind engines. The analysis of maps of the period 1928–1936 revealed the existence of dikes along the major canals and drainage ditches in the form of road embankments. In addition, wetlands were crossed by ground embankments which allowed movement around the wetland. However, there were no flood protection facilities both along the major rivers and lakes. Due to the hydraulic contact of the lakes with the sea through the estuary sections of the rivers Łupawa and Łeba, the low-lying areas around the lakes were flooded periodically. Flooding occurred when the sea water surged into the lakes during storms or in the case of blocking the outflow from lakes as a result of higher sea levels. This problem was solved just before the outbreak of the World War II, when a system of 21 polders was built, from which water was pumped out by pump stations (Cebulak 1984).

As a result of the engineering works carried out at the turn of the 19th and 20th century, the surface extent of drained areas increased greatly. A forced water circulation caused increased volumes of discharge, especially from waterlogged areas. As a result, the groundwater table lowered and consequently water resources were depleted as well as the extent of permanently damp areas was reduced (Fig. 5). In the Łeba glacial valley the wetlands shrank drastically forming isolated enclaves. A similar situation was observed in the wetlands surrounding lake Łebsko from the south and south-west. Whereas the areas in the belt between Łebsko and Sarbsko were completely drained.

The period after the World War II was initially characterized by reconstruction and repair of neglected and damaged pre-war hydrotechnical devices (Rolka 1995). Soon, however, new irrigation concepts arose, subjected to emerging state farms in the area of the Gardno-Łeba Lowland, and modified the earlier activities. The cartographic information on the maps of 1976–1986 reveals that there were about 30 such farms in

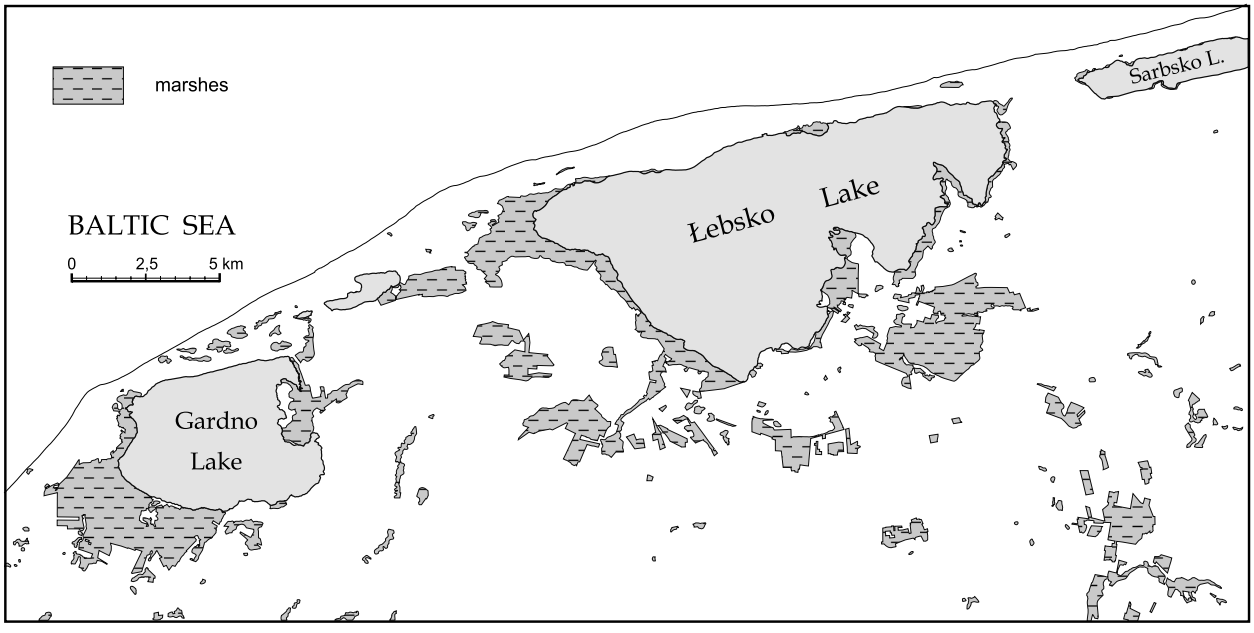

Fig. 5. Extent of wetlands in the Gardno-Łeba Lowland in the early 20th c.

this area, aimed mainly at cattle and fish farming. As a result of the works carried out and the new technological possibilities, the irrigation took regular geometric forms then, as opposed to the previous ones (Fig. 6). Some of the previous concepts were abandoned, as evidenced by the decrease in drainage ditches density in the Łeba river valley east of Wolinia or on a swamp located south-west of the lake Gardno, near the village Dębina. At the same time, the areas where drainage had so far been only basic, gradually underwent irrigation. This way, the rest of the Łeba valley, Rzuskie and Ciemińskie swamps, marshes north of the village of Żelazo and Wielkie Bagno Objazdy, were utilized. In connection with opencast peat mining on an industrial scale (Peat Mine in Krakulice), the hydrographic system of The Great Swamps situated south-east of lake Łebsko, was also transformed. This resulted in the formation of water bodies in the extraction pits.

Numerous other changes was recorded: e.g. the river Grabownica, partly Bagienica, as well as fragments of the river Łupawa above Smołdzino, were regulated. In the Łupawa valley some of the meanders, seen in the record as oxbow lakes, were cut off, and artificial reservoirs for fish breeding were constructed. In connection with the operation of polder systems equipped with water pumping devices, the estuary sections of minor and major rivers, flowing into the coastal lakes, were walled, and the lakes themselves were surrounded by flood embankments. Changes of preferences in the post-war irrigation caused point, secondary waterlogging of some areas, recorded on a very small local scale. In fact, however, groundwater resources underwent further depletion, particularly in the areas of peat mining (Wielkie Bagna) and on wetlands lying south-west of lake Gardno (Wielkie Bagno Objazdy – The Great Objazda Swamp; Fig. 7). It is demonstrated by the contemporary names of objects on the map: Objazda Meadows, Smołdzińskie Meadows and others, which replaced the word previously used i.e. *swamp*.

The establishing of protected areas in the form of the Słowiński National Park and nature reserves, was of great importance in the post-war system of water management of the Gardno-Łeba Lowland. Their rank increased especially after the Polish political transformation (1989), and the liquidation of state-owned farms (1993), which is why today, in the area covered by the study, the activities connected to improvement of water relationships through the protection of fragmentally preserved wetlands, have become more important. The Słowiński National Park and the local forestry authorities take leadership in this field. Protective action strategy is going to establish reserves, piezometric monitoring and

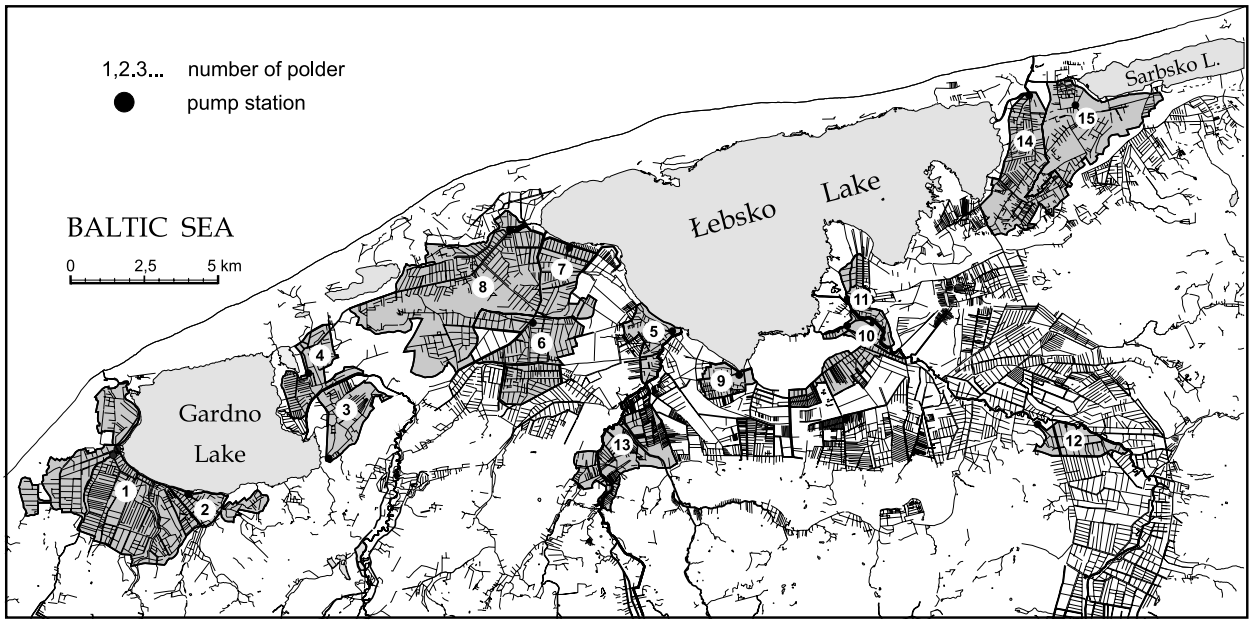

Fig. 6. Polders and pump stations in the Gardno-Łeba Lowland in the early 20th c.
(number of polder corresponds to the number in the Table 1)

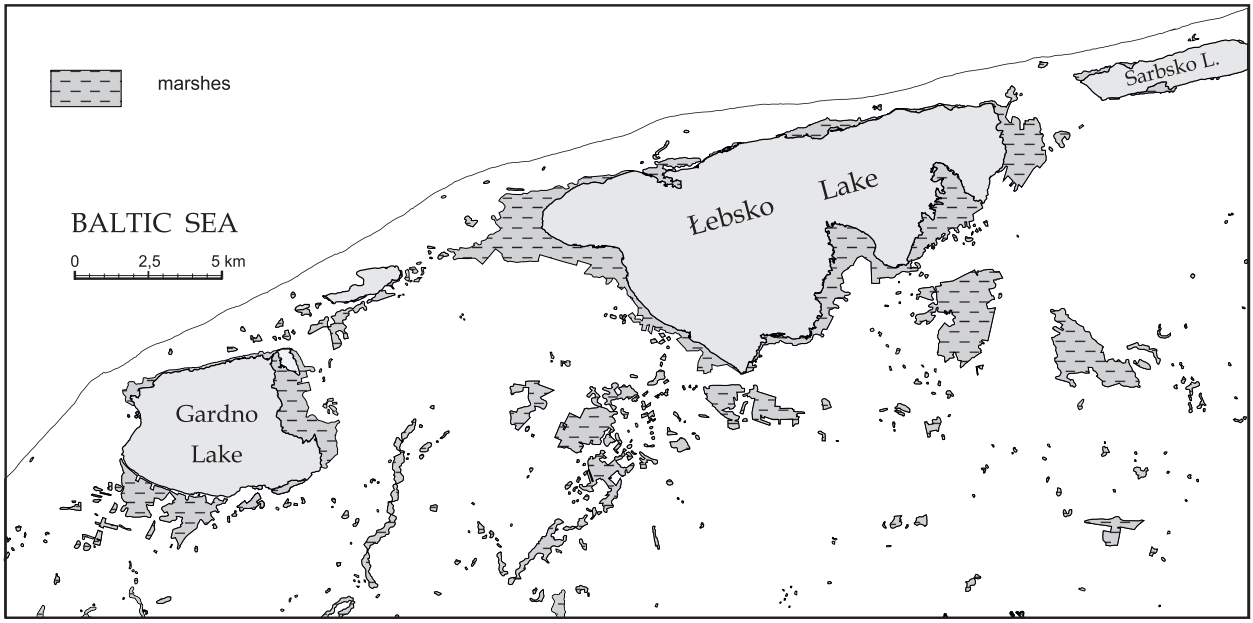

Fig. 7. Extent of wetlands in Gardno-Łeba Lowland in the second half of 20th c.

stopping the excessive discharge of water from peat bogs through the construction of valves on banding drainage ditches. Such work has already covered Kluki, Żarnowskie (The Great Swamps) and Izbickie swamps.

Nevertheless, water management related to flood protection and providing of optimal conditions for agricultural production is still carried out around the areas protected by the Water Law. Currently in the area of the lowland, there are 15 polders with operating pumping stations, discharging waters directly or indirectly into the coastal lakes: Gardno, Łebsko and Sarbsko. Some of the polders in whole or in part are located in the Słowiński National Park (Gardna VII, VIII Gardna, Gardna IX–X, Kluki IV–I, IV–II Kluki, Gać). The largest quantity of water is pumped out in periods of increased precipitation (especially in autumn, winter and summer), in snowmelt period and during storms. In water balance of some polders (Gardna VII – lake Gardno catchment and Kluki IV–II and Lisia Góra – lake Łebsko catchment), the quantity of water pumped out exceeds precipitation (negative water balance). For the mentioned polders, the discharge rate in 2003–2007 was over 1000 mm·year^{-1}, exceeding the annual total rainfall for the area by about 40% (Table 1). It follows that the polders constitute a periodical local drainage base for the area adjacent to the polders, which may adversely affect the introduced protective measures.

Changes in land use

Until the 18th century, the water conditions prevailing in the Gardno-Łeba Lowland in the form of extensive wetlands, did not facilitate the development of agriculture or settlement. Only the irrigation measures, introduced at the end of the century, led to an increased availability of land for use. Waterlogged areas between lakes Gardno and Łebsko (called Smołdzińskie swamp – Przybynin, Łokciowe) and Łebsko and Sarbsko started to be used as wet hay meadows for grazing specially imported cattle and sheep, resistant to harsh and humid conditions. Settlers from the Netherlands were brought in for the irrigation and maintenance of dairy farms (called holendria). Cultivated fields occurred occasionally taking up small enclaves in the existing dairy farms (Malotki 1932, Szalewska 1984). Much larger areas of fields occupied higher grounds of the moraine plateau surrounding the lowland.

The development of agricultural drainage system in the second half of the 19th century caused an increased in the area occupied by meadows and arable fields. In the face of a decline in demand for wool, pastures were commonly converted to croplands. Around 1880, the structure of land use in the Gardno-Łeba Lowland and areas immediately adjacent to it, was as follows: arable land occupied 27.7%, pasture – 15.6%, meadows – 13.4%, forests – 12.9%, water, de-

Table 1. Mean annual quantity of water discharged from polders in 2003–2007 (data from pumping stations working in the studied area).

No.	Polder	Location	Area [ha]	Average runoff 2003–2007	
				Runoff index [mm]	Specific discharge q [$dm^3 s^{-1} km^{-2}$]
1.	Gardna V (awaryjna)	Dębina	1700	19	0.59
	Gardna V–VI	Dębina		360	11.42
2.	Gardna VII	Retowo	182	**1278***	**40.58**
3.	Gardna VIII	Gardna Wielka	300	**889***	**28.22**
4.	Gardna IX–X	Gardna Wielka	326	131	4.15
5.	Kluki I	Kluki	184	332	10.23
6.	Kluki III	Łokciowe	564	gravity runoff	
7.	Kluki IV–I	Łokciowe	280	114	3.61
8.	Kluki IV–II	Przybynin	685	**1201***	**38.11**
9.	Lisia Góra	Lisia Góra	240	**1123***	**35.66**
10.	Izbica	Izbica	340	219	6.97
11.	Gać	Gać	190	551	17.49
12.	Cecenowo	Cecenowo	183	18	0.06
13.	Skórzyno	Skórzyno	325	704	22.34
14.	Łeba-Miasto	Łeba	599	175	5.55
15.	Nowęcin I	Nowęcin	434	88	2.78

*Bold text indicates the runoff exceeding the average value of precipitation.

veloped areas, areas of minerals extraction and wasteland (including wetlands and dune sands) together accounted for 30.4% (Szalewska 1984). At the turn of the century the area of meadows and arable fields still increased, mainly due to the development of cattle breeding and the introduction of fodder crops and potatoes (Stelmachowska 1963). The most significant changes covered the Łeba glacial valley where marshes were transformed into dry and wet meadows, as well as the areas between lakes Gardno – Łebsko and Łebsko and Sarbsko. Wet meadows accompanied the lake shores and regulated sections of the rivers between the cut off oxbows. In the remaining fragment of the Gardno-Łeba Lowland the characteristic mosaic structure of land use developed.

In the early years after World War II (1945–1950) negligence of irrigation facilities and equipment, resulted in exclusion from production of the areas of wet meadows around Smołdzino, Gardna Wielka, Izbica, Ciemino, Kluki, areas south of lake Łebsko, of lake Gardno, in the Łeba glacial valley and in the river Pustynka valley (Szalewska 1984). In addition, some of meadow complexes (between Smołdzino and Kluki, in the area of Krakulice and Łeba and Sarbsko Spits) were intended for military use and turned into wastelands.

The establishment of state-owned farms (PGR) adapted the area of the Gardno-Łeba Lowland to large space agriculture. There were approximately 30 such farms oriented primarily on cattle and pigs breeding. The high concentration of livestock required provision of fodder facilities, so in terms of agricultural technology, the area started to be used mainly as hay meadows. The production of dry fodder on an industrial scale was served by green fodder dryers, located in Główczyce, Ciemino, Wolinia, Cecenowo, Łokciowe, Przybynin, Górki, Krakulice and in Objazd (Szuflita 1969 Kochanowicz, Hałuzo 1992).

After the resumption of irrigation works and their intensification in the 1970s, low peatlands around Czołpino, Dębina, Objazda, Smołdziński Las, Smołdzino, Łokciowe and Żelazo, were subjected to further desiccation and conversion into dry meadows. Wet meadow sites were preserved only in clusters surrounding the southern shores of lake Łebsko and around Kluki and Lisia Góra.

In time, they were completely excluded from use due to difficult conditions, and have undergone a rush succession.

In the period from 1945 to the 1980s, the area of farmlands shrank significantly. According to the cartographic data of 1979–1986 in the Gardno-Łeba Lowland, the areas intended for crops were found in the vicinity of Objazda, Gardna Wielka, Smołdzino, as well as Siecie and Witków, and in the area of Izbica, Żarnowska, Krakulice and Nowęcino. Whereas the main pasture areas were around Rowy, Dębina, Objazda and Smołdziński Las. During the 20th century, they occupied no more than 3 000 hectares. After the collapse of state-owned farms, most of the agrarian used areas transformed into wasteland.

An important type of land use, marked on maps from the early 19th century, were forests (Fig. 8). Marshy coniferous forests and riparian forests dominated, covering Wielkie Bagno Objazdy and the vicinity of Dębina (Schönwalde), north-western and south-western ends of lake Łebsko (Klucki Las – Das Lochzer Wald), area of Izbica, Gać, Żarnowska. They also covered the Łeba glacial valley and the Główczycki Stream valley (Schoriner Bach) and its tributary – the Skórzynka (Glowitzer Grenz Bach). Large forest complexes occurred in the areas of moraine hills to the north of Charbrowo and in the edge zone around Machowinko. The forests stabilized the sand dunes in the area of the Gardno Spit and in fragments of the Łeba Spit. The Sarbsko Spit was characterized by a lack of forests.

In the late 19th century and in the first half of the 20th century the forest areas were altered by deliberate actions. The afforestation works and felling were carried out with varying intensity until 1944. The growth of agricultural awareness caused the abandonment of use of areas with poor quality class soils, which were then subject to natural succession or intentional plantings (Schlechtl et al. 2004). As a result of plantings carried out in the 1920s and 30s, the Sarbsko Spit was also fixed (Mieńko et al. 2002), while more than 440 hectares of land underwent afforestation on the Gardno and Łeba spits since 1890.

The main afforestation works took place in 1903–1912 and 1923–1932. They covered mainly the belt from lake Gardno through Dołgie Wielkie to Łebsko, as well as the area of Rąbka and Łeba. The forest cover increased in the southern part of Rowokół Hill and fragmentarily in the complex between Gać and Żarnowska. At the same time, in other places of the Gardno-Łeba Lowland deforestation occurred. The area of Klucki Las decreased substantially, partially due to fire (Piotrowska 1997, Schlechtl et al. 2004). The area of tree stand shrank in the Great Objazda Swamp (and the marshes near Żelazo, which were converted to meadows (Fig. 9).

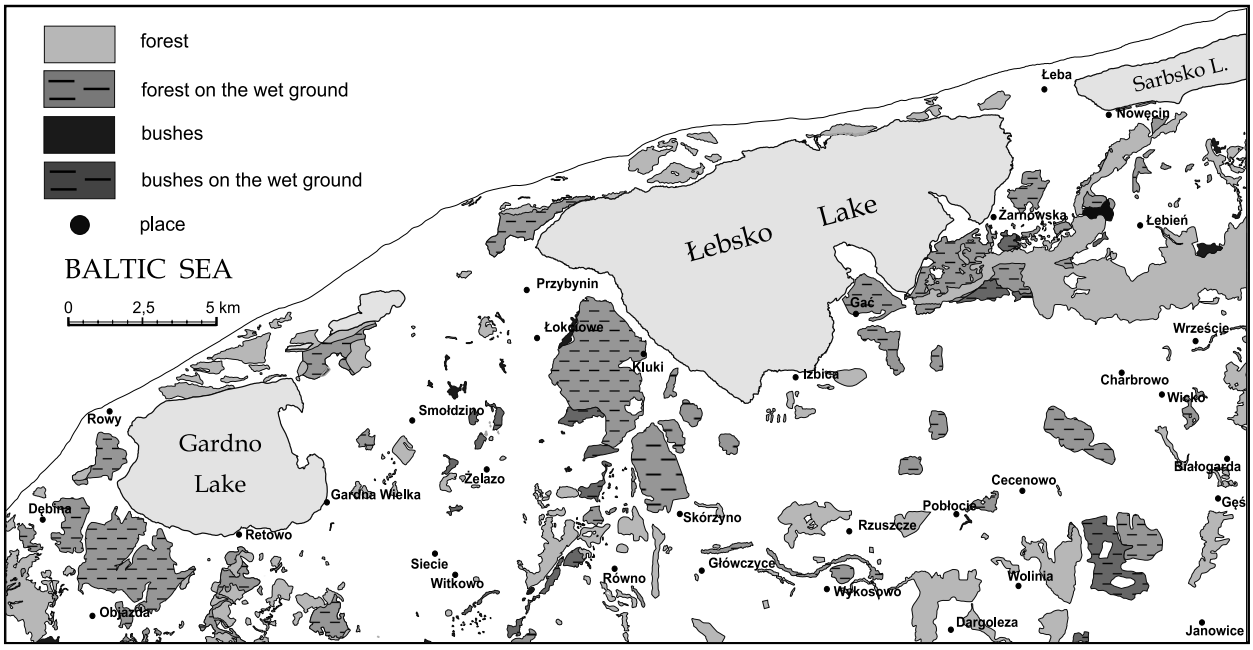

Fig. 8. Extent of forests in Gardno-Łeba Lowland in the early 19th c.

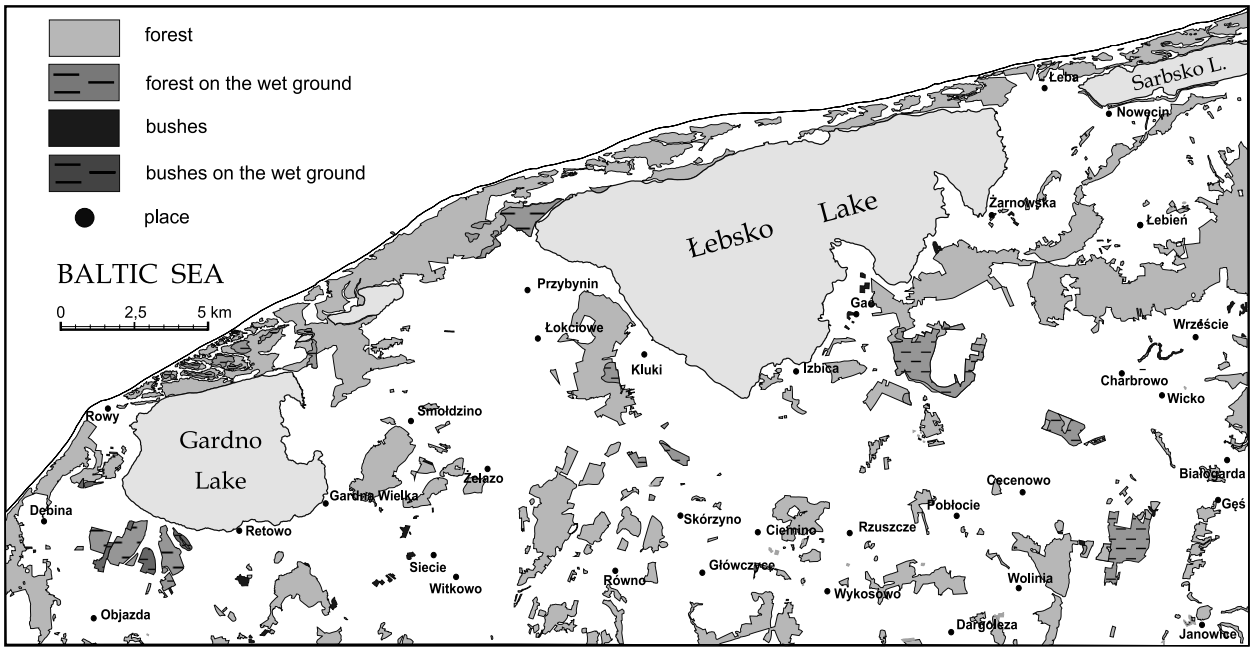

Fig. 9. Extent of forests in Gardno-Łeba Lowland in the early 20th c.

After the war, until 1986, the forest area of the Gardno-Łeba Lowland increased. The lands with low value soils or abandoned after 1945 were afforested. In 1947–1968 in the area of the south-eastern shore of lake Łebsko in Żarnowska forest complex, the abandoned settlements of Bolesławiec and Babi Dół were planted (Schlechtel et al. 2004). Forest areas also increased on former farmland between the river Łupawa and the village Żelazo in the complex of Rowokół (Piotrowska ed. 1997), around Żelkowo and Klucki Las (Fig. 10).

Strong scattering of small forest enclaves appeared in the areas of the Izbickie, Rzuskie and Ciemińskie swamps and the Łeba glacial valley. Until 1966, there were more than 10 000 hectares of woodland planted (Szalewska 1984). However, parasites have reduced the tree stand on the Spit, in Klucki Las and in area of forest between Gać and Żarnowska.

The activities transforming the natural water relations over the last 200 years included extraction of minerals, mainly peat. It was directly associated with draining of the area to obtain the deposits. The cartographic data of 1836–1837 informs about point peat mining, scattered across the whole area of the lowland, already in the early 19th century, since peat was used as fuel, lining for livestock and crop fertilizer. Extraction sites were found in the Łeba glacial valley, in Wielkie Bagna and in the vicinity of Żarnowska on the Łebskie, Nowęcińskie and Izbickie swamps. Substantial areas were occupied by peat exploitation within the swamp located in the estates of Żelazo, Witków, meadows and pastures of Siecie, west of Klucki Las and on wetlands between Gardna Wielka and Smołdzino. Wielkie Bagno Objazdy swamp was not exploited. Locally there was also marl quarrying: in the village of Bukowa, Objazda and Siodłonie. Brickyards were found around Charbrowo, in Równo, Wolinia and just beyond the Gardno-Łeba Lowland in Janowice and Dargoleza.

At the turn of the centuries, peat and sand mining developed. The scale of their impact on the water relations is illustrated by the data provided by Szalewska (1984), who estimated that until the 1880s, the areas of peat, sand, gravel and clay extraction covered the area of 1650 ha. Peat was extracted on the western shore of lake Gardno near Dębina, further on the Wielkie Bagno Objazdy, where the early twentieth century industrial exploitation started, as well as on the outskirts of Klucki Las. Large-area works continued in the Izbickie swamp and on the high bog between Gać and Żarnowska. In the late 19th century and the first decade of the 20th century, peat was also mined in the Skórzynka valley around Ciemino and Główczyce. Whereas sandpits functioned in the areas including the region of Ob-

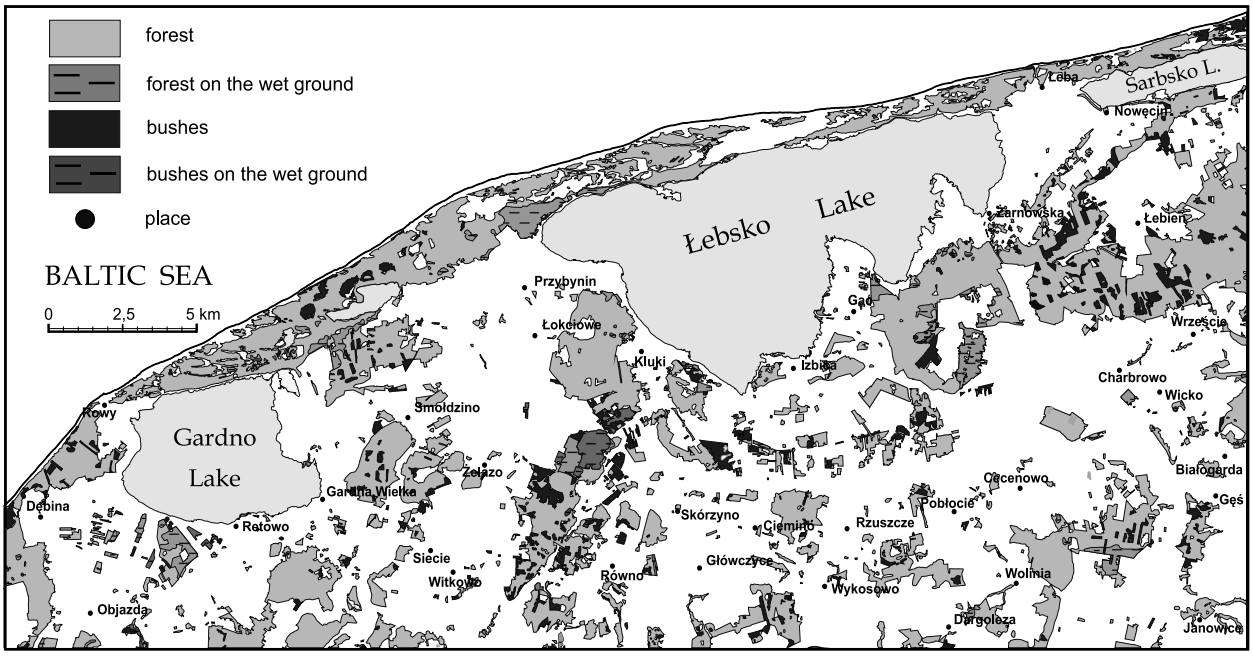

Fig. 10. Extent of forests in Gardno-Łeba Lowland in the second half of 20th c.

jazda, Smołdzino, Gardna Wielka, Główczyce and other settlements. Sands were extracted for the construction of roads and irrigation facilities, so over time their quantity decreased as a result of exhaustion of the deposit or the completion of the task. Thus, the number of extraction sites decreased by 45% in 1936 compared to 1880. In the late 19th century in the Gardno-Łeba Lowland there were also several brickyards connected to local resources. Their produce included drainage pipes for local agricultural drainage system (Lindmajer 1981). According to the cartographic data from the first half of the 20th century, the number of brickyards reduced to 5.

According to the record of the maps of the second half of the 20th century, peat extraction continued in the Pustynka valley, Izbickie swamp and Wielkie Bagna, where since 1948, the Peat Plants from Krakulice have operated on an industrial scale in the area of 1600 hectares (Jasnowski 1990). The thickness of the excavated material is about 20 cm y^{-1} (Pawłat 1997). Moreover, 13 gravel pits were found in the border zone of the upland and the Gardno-Łeba Lowland (in the area of Lotki, Żelkowo, Bukowa, Lisia Góra, Łokciowe, Następowo, Wrzeście, Nadolnik, Rozgórze and Pobłocie). Only one brickyard in vicinity of Charbrowo continued its activity.

Stages of hydrologic changes

The conducted research made it possible to distinguish seven stages of the hydrographic network and land use changes, resulting from agricultural drainage system works of various degrees of intensity. Stages were determined based on the interpretation of changes recorded on cartographic materials and in the literature.

The first period (1750-ca. 1800) was characterized by pioneering drainage works (recorded on maps) in general and detailed drainage, in order to improve soil conditions. The canals functioning until the present day were created at that time: Łebski, Żarnowski, Gardno-Łebsko, Łupawa-Łebsko. Rivers and streams preserved a natural type of their courses. Wetlands dominated in the land use structure, and the few pastures and meadows created isolated enclaves occurring between lakes Gardno-Łebsko as well as Łebsko and Sarbsko.

The years 1800–1840 were a period of stagnation, caused by a lack of funding for the maintenance of the existing irrigation infrastructure and further investments, due to the difficult political and economic situation of the Prussian state. This resulted in a partial blockage of the canals and ditches in the Gardno-Łeba Lowland.

After the period of stagnation, there was a phase of reconstruction and maintenance of the previously neglected drainage system (1840–1880). This period was characterized by the foundation of legal basis and then the establishment of water institutions and companies dealing with water management works (*Koszalin Melioration Fund* – 1846, the *Company for the melioration of the* Łeba *marshes* – 1868). The irrigation facilities located in the area of Przybynin and Łokciowe (Smołdzińskie wetlands) were renovated and the canal system in the Łeba glacial valley was restored.

The next phase (1880–1945) was marked by the largest changes in the hydrographic network of the Gardno-Łeba Lowland, initiated by the implementation of the *Law on Water Companies* (1879) and the *Provincial Swamp Commission for Pomerania* (1897) (Dreyer 1913, Lindmajer 1981). As a result, the beds of the Łupawa and Łeba glacial valleys and smaller watercourses: Pustynka, Skórzynka, Główczycki Stream, Brodna etc., were subjected to the regulation of discharge conditions. Large areas of Wielkie Bagno Objazdy (The Great Objazda Swamp) and marshy areas around lake Łebsko and Sarbsko were drained and included in the polder drainage system. The irrigation works proceeded with varied intensity, hence the water network density varied too. The highest concentration of ditches occurred in the area of Ciemińskie swamps and around the village of Wolinia, of over 20 km km^{-2} (Chlost 2010). A rapid development of irrigation resulted in changes in the types of land use. The area of meadows, arable fields, forests and mining activity (peat extraction) increased.

The post-war years 1945–1965 were the period of a reduced capacity of the drainage systems due to neglect and lack of maintenance. As a result, the areas in the vicinity of coastal lakes and Łeba glacial valley, were subjected to secondary waterlogging and exclusion from agricultural production.

The resumption and further development of drainage works took place in 1965–1993. The purpose of irrigation projects of this period, was to adapt the area to the needs of industrialized farming methods and mechanization of agriculture (state farms). The concept of drainage changed, with the emphasis put on underground drainage methods with drains and siphons. The number of detailed ditches and their parameters (depth and width) decreased. As part of the works, smaller watercourses were regulated and units with gravitational water flow and polders of forced circulation were built. These actions resulted in a further reduction of wetlands, especially in the area of Wielkie Bagno Objazdy (The Great Objazda Swamp), and a strongly geometrized water network. Farming in the Gardno-Łeba Lowland focused on cattle and pigs breeding, so in terms of agricultural technology its area was used as pastures and hay meadows. There was a further increase in forest cover. An important type of use of wetlands and meadows was peat extraction, locally taking an industrial scale (Peat Plant in Krakulice).

The last stage of changes in the water relations of the Gardno-Łeba Lowland is dated from 1993 to the present year. It is a time of adapting the existing hydrographic system to changing land uses after the collapse of state-owned farms. Protection of the environment has become the priority. The growing importance of the Słowiński National Park was marked, especially in the field of wetlands reclamation.

The image of contemporary water relations in the Gardno-Łeba Lowland is a reflection of man-made drainage and regulatory procedures advancing over 200 years. They resulted in a new hydrographic system which caused the transformation in the organization of natural underground outflow into artificially generated drainage by means of a dense surface network of canals and ditches. The originally retentive nature of the lowland with its rich groundwater resources, has been reversed, and today it performs a transit function. The protective measures introduced gradually are aimed at the restoration of water conditions to a close to natural state.

A comparison between the topographic maps from the initial (1836–1837) and end (1976–1986) periods, allows for the identification of areas subjected to the largest and smallest changes due to anthropogenic pressure (Fig. 11). The areas of greatest change are indicated by either the density of the water network, loss of wetlands or a forest cover change. Areas with the greatest intensity of changes (three of these components changed), are the regions of peat mining within the swamps: Kluki, Wielkie Bagna Gać, Ciemińskie, Rzuskie,

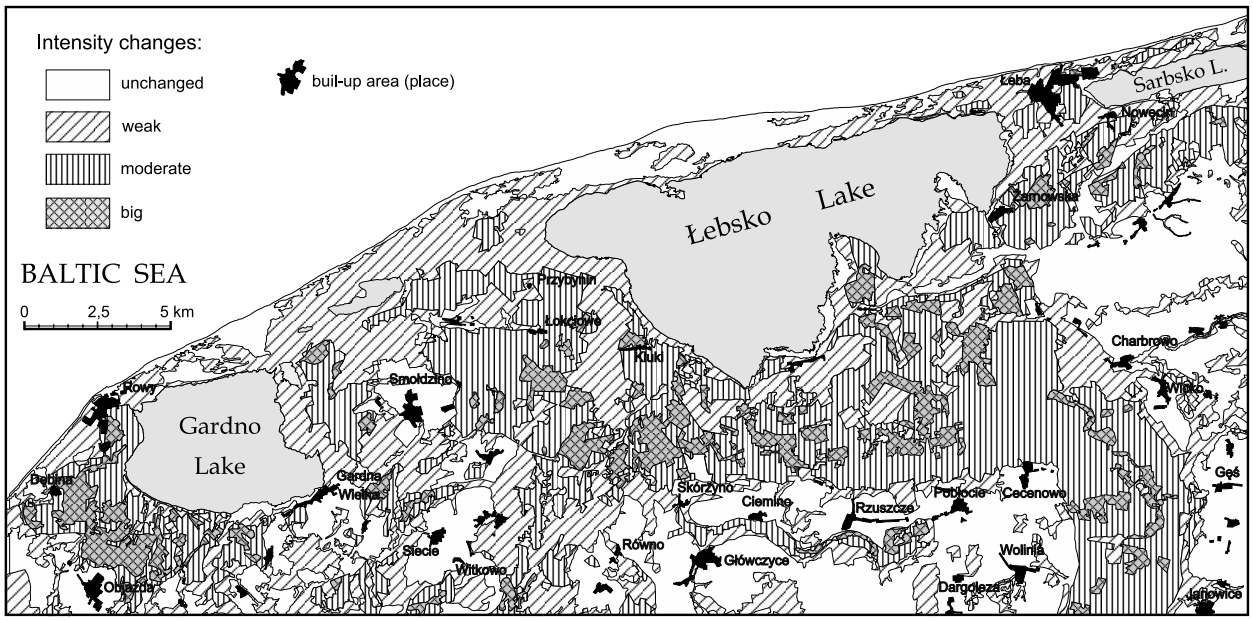

Fig. 11. Intensity of anthropogenic changes in water relationships of Gardno-Łeba Lowland in the period from the first half of the 19th c. to the end of 20th c.

the area around the Wielkie Bagna Objazdy (The Great Objazda Swamp) and the vicinity of Dębina. Areas of moderate transformations (only two components changed) are the river Łeba glacial valley, and areas where the polders were created. Areas least changed (only one component changed), are the places where, despite the irrigation procedures, wetlands persisted, as on the shores of lakes Łebsko and Gardno. The upland areas surrounding the Gardno-Łeba Lowland are characterized by a complete absence of evidence of significant changes.

Conclusions

The melioration works carried out in the 19th and 20th century in Gardno-Łeba Lowland contributed to diminishing of groundwater resources, resulting in often irreversible elimination of water-logged areas. The registered changed, documented on the scale of the analysed lowland, can however be referred to a much broader spatial scope. This scope covers not only the area of Poland but the lowland zone of the European continent, especially Baltic countries, such as Estonia (Kimmel et al. 2010). According to estimates by Joosten and Clark (2002), losses of water-logged ecosystems in Europe as a result of transformations into arable land, meadows and pastures reach 50–90%. It is highlighted by contemporary research that degradation of water-logged areas, especially peatlands, is related mainly to their drainage for farming purposes (Wild 1997, Rupp et al. 2004) or peat exploitation (Chapman at al. 2003).

The drainage of water-logged areas in Poland and other post-communist countries created favourable conditions for large-scale agriculture, with its peak after WW2. In Gardno-Łeba Lowland, due to a water-logged character of the ground, the best form of land use appeared to be meadows and pastures, providing fodder for large numbers of livestock. Up to 1980, animal population here was over 27 000 (sheep, cattle, swine) on the total area of the lowland of about 370 km^2. Biomass production in the lowland met their feeding needs completely. After the political system transformation, which resulted in resignation from the management method based on mass production, the existing melioration network became useless. A considerable part of meadows and peatlands ceased to be agriculturally used. Some ditches got blocked due to lack of maintenance, and some were intentionally eliminated within the protection zone of the Słowiński National Park. Only the old original ditch systems retained their role (canals: Łebski, Żarnowski, Gardno-Łebsko and Łupawa-Łebsko), as it was the case in Żuławy Wiślane.

The concept of reconstruction of groundwater resources based on resignation from proper

maintenance of melioration infrastructure did not completely meet the goal in terms of nature protection. The abandonment of mowing and grazing activated vegetation succession processes, which are often negative from the ecological perspective and may result in a decrease in biodiversity. It appeared that there are bird species (Charadriiformes) which require regular mowing and consequently lowering of water level. An example of such an area in Gardno-Łeba Lowland is polder IX–X. Another example is the reintroduction of extensive animal grazing in areas of occurrence of halophytes (eastern bank of Lake Łebsko). This is a consequence of a completely new approach to protection and restoration of water-logged areas on degraded land, following the introduction in Poland and other European countries of the Natura 2000 ecological network. The functioning of this network is supported by agri-environmental programmes which indicate rational methods of management of water-logged habitats (Kucharki, Stypiński 2009). Practically the whole SPN is covered by the Natura 2000 network, and it constitutes over 2/3 of Gardno-Łeba Lowland.

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