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Sedimentation rates and erosion changes recorded in recent sediments of Lake Piaseczno, south-eastern Poland

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This paper presents the dating results and basic analyses of recent sediments from Lake Piaseczno. The age of sediments was determined using the ^{210}Pb method and constant flux : constant sedimentation (CF : CS) model. The estimated timescale was in agreement with the AMS^{14}C date from the base of the core. The mean sediment accumulation rate during the last 100 years was calculated as 0.025 g cm^{-2} a^{-1}. Based on the radiocarbon date, the rate of sediment accumulation below the ^{210}Pb dating horizon was estimated as 0.066 g cm^{-2} a^{-1}. The variability of main physical properties and sediment components along the core was analysed as well. The sediments were characterised by a very high water content (>80%). Carbonates were either not present or at a very low level (<1%). However, organic and minerogenic matter variability represents an interesting record of increasing erosion intensity in the catchment area. Analysis of archival cartographic materials demonstrated that the most likely reason for the enhanced transport of minerogenic matter to the lake was deforestation caused by human activity in the beginning of the 20th century.

Key words: lake sediments, ^{210}Pb, sedimentation rates, erosion changes, deforestation, south-eastern Poland

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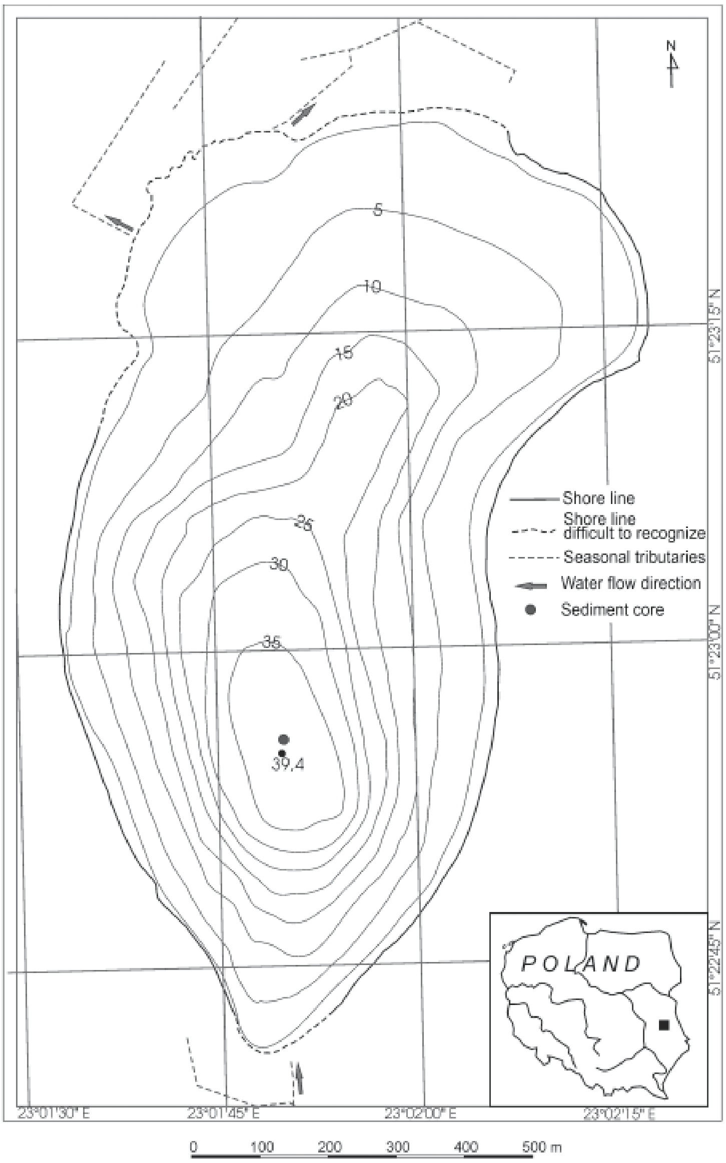
INTRODUCTION

The Łęczyńsko-Włodawskie Lakeland is located in south-eastern Poland and consists of unique lake systems which have been investigated for many years (e. g. Wilgat, 1954; Harasimiuk et al., 1998). The evolution of these lakes has been examined in a long-time perspective, including their origin and Late Glacial / Holocene changes. Detailed research was performed for several lakes (Łukcze, Karaśne, Moszne, Perespilno), based on sediment cores, palaeobiological analyses, radiometric dating and other methods (e. g. Bałaga, 2002, 2007; Bałaga et al., 1998, 2002; Goslar et al., 1998). In contrast, recent sediments, providing a record of environmental changes during the last several hundred years, have not been investigated so far.

To fill this gap, a multidisciplinary research project on changes of the Łęczyńsko-Włodawskie lakes during the last millennium was carried out. The project included research of Lake Piaseczno recent sediments in terms of radiometric dating, physical properties, chemical composition and palaeobiological proxies. In this study, we present results of ^{210}Pb dating and the basic composition of short core sediments collected from the deepest part of Lake Piaseczno.

STUDY SITE

Lake Piaseczno is the deepest lake in the Łęczyńsko-Włodawskie Lakeland. In the years 1991–2006, its water level varied from 169.1 to 170.3 m a. s. l. The basic morphometric features of the lake are shown in Fig. 1 (Turczyński, in press).



surface area – 75.74 ha	shoreline length – 3715 m	volume – 8127.6 tys. m^3
max. length – 1413 m	max. depth – 39.4 m	epilimnion depth – 4.8 m
max. width – 762 m	mean depth – 10.7 m	mean bottom slope – 5.33°

Fig. 1. Location and bathymetric contour map of the study lake (Turczyński, in press)
1 pav. Tirtojo ežero padėtis ir batimetrinis žemėlapis

The catchment area of Lake Piaseczno is 312 ha. The altitude within the catchment ranges from 169.3 (the lake shoreline during field work in 2006) to 176.0 m a. s. l. The uniform topography of the catchment contrasts with steep slopes of the lake basin, which is of a concave cone shape (depth index 0.27) and has the greatest mean bottom slope (5.33°) in the group of Łęczyńsko-Włodawskie lakes. Wojciechowski (1991) emphasised this contrast and paid attention to the unusually rare occurrence of surface runoff in this area. Inflows and outflows occur only during snow melting after snowy winters. In practice, during almost the whole year the catchment has no outflow. Hydrographically, it belongs to the upper Tyśmienica drainage area without surface connection to the main river. The specific location of the Lake Piaseczno catchment in the watershed zone means that it is not included in the Wieprz–Krzna Channel system which protects the lake waters from the influence of the channel waters.

Presently, both Lake Piaseczno and its catchment are intensively used for recreational purposes. From the late sixties of the 20th century, many bungalows have been built close to the lake shore. The lack of appropriate sewage systems is still the main danger for the hydrosphere in that area (Michalczyk, Turczyński, 1998).

The southern part of the catchment is located close to a mining area (KWK "Bogdanka"). So far, it has not influenced the lake ecosystem, but the further exploitation of coal resources might be negative for the lake environment (Michalczyk et al., 2007).

METHODS

Field work was carried out in February 2006. Three cores of recent sediments were collected from the deepest part of the lake (Fig. 1) by a Beeker sampler (Eijkelkamp, the Netherlands), a piston corer with a 58 mm inner diameter core tube. The equipment and coring technique provide an undisturbed structure and low compression of the sediments. Upon collection, the cores were transported to the laboratory and subsampled at intervals of 1 cm by pushing the cores upwards. Sediment samples were placed in tight plastic containers and stored at 4 °C until analysis.

Water content was determined by drying the samples at 105 °C to constant weight. Weight loss on ignition (LOI) was used to determine the main components of the sediment according to the procedure described by Heiri et al. (2001). The organic matter and carbonate contents were determined by burning samples at 550 °C for 4 h, followed by combustion at 925 °C for 2 h, respectively. From the remaining part of the sediment, biogenic silica was removed by heating in 2 M Na_2CO_3 (4 h, 90 °C) in compliance with the procedure proposed by Eggimann et al. (1980). The final residue after filtering and drying was identified as minerogenic material constituting only an allochthonous element (Håkanson, Jansson, 2002).

The sediment core was dated using ^{210}Pb. Details of the method have been reported by various researchers (e. g. Appleby, 2001; Appleby, Oldfield, 1978; Krishnaswamy et al., 1971). The ^{210}Pb activity was measured following the procedure that had been used previously by the authors for lake sediment analysis (Tylmann, 2004, 2005; Tylmann et al., 2007). ^{210}Pb was determined indirectly by measuring ^{210}Po in an alpha spectrometer. A trace of ^{209}Po was added to a sample of dried sediment (0.2 g), and the sample was wet digested (HF and $HClO_4$). ^{210}Po and ^{209}Po were then spontaneously deposited on silver disks. Activities were measured using a 7200-04 APEX Alpha Analyst spectrometer (Canberra) equipped with PIPS A450-18AM detectors. The average counting time was 24 hours.

The total ^{210}Pb is expressed as measured activities ± counting variability (one standard deviation). Unsupported ^{210}Pb activity was determined by subtracting the background ^{210}Pb activity obtained for the lower zones of the core, with the assumption of constant supported ^{210}Pb activity along the sediment column. The uncertainty of unsupported ^{210}Pb was calculated according to the rule of error propagation. The constant flux : constant sedimentation (CF : CS) model was used to calculate the sediment age and sedimentation rate. The CF : CS model is applied when sedimentation rates are steady, and unsupported ^{210}Pb activity decreases with depth exponentially according to the law of radioactive decay (Appleby, 2001; Oldfield, Appleby, 1984).

One sample was taken for AMS^{14}C dating from the analysed core. Plant macrofossils were found in the level 75–77.5 cm and, after wet sieving, birch seeds were separated and sent to the Poznan Radiocarbon Laboratory. The obtained date was calibrated for calendar years using the Intcal04 calibration curve (Reimer et al., 2004) and OxCal 3.1 software (Bronk Ramsey, 2001).

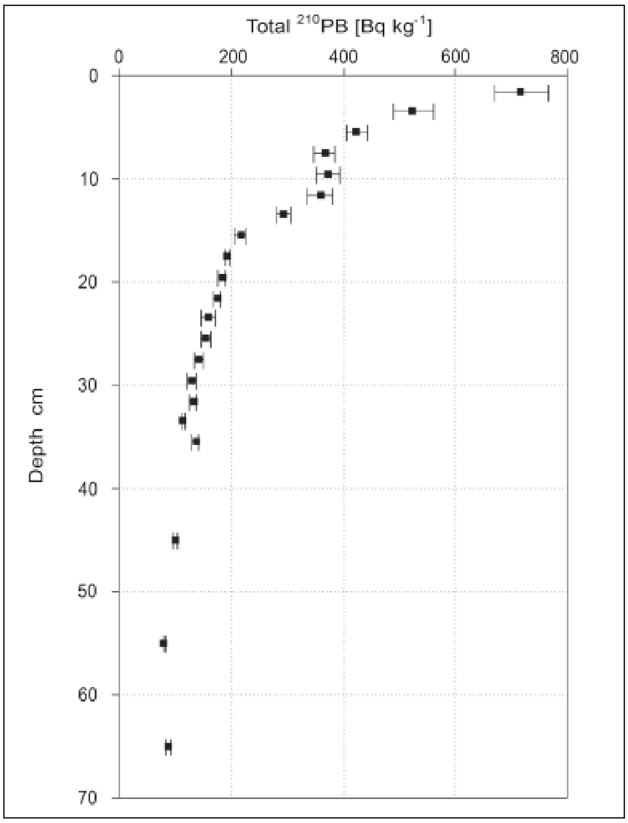


Fig. 2. Specific activity of total ^{210}Pb in the investigated core
2 pav. ^{210}Pb specifinis aktyvumas tyrinėtame gręžinyje

RESULTS AND DISCUSSION

Chronology and sedimentation rates

The activity of unsupported ^{210}Pb decreases with depth exponentially to the background value at a depth of 40 cm (Fig. 2). Irregularities in activity decrease were observed only at the level 9–14 cm, but they were insignificant. Supported ^{210}Pb was calculated as a mean value from the depth 40–70 cm, and it was 91 ± 3 Bq kg^{-1}. The activity of unsupported ^{210}Pb, plotted on a logarithmic scale, decreased with depth, expressed as a cumulative dry mass almost linearly (Fig. 3), and the estimated exponential equation explained 95% of variance. Therefore, it may be stated that the assumptions of the CF : CS model are fulfilled, and unsupported ^{210}Pb activity in sediments changes with the cumulative dry mass according to the formula:

$$C_{(m)} = C_{(0)}e^{-\lambda m/r},$$

where:

$C_{(m)}$ – unsupported activity at depth *m*;

$C_{(0)}$ – unsupported activity at the sediment–water interface;

λ – ^{210}Pb radioactive decay constant (0.03114 a^{-1});

m – depth measured as cumulative dry mass (g cm^{-2} a^{-1});

r – dry sedimentation accumulation rate (g cm^{-2} a^{-1}).

Mean sediment accumulation rate (SAR) can be determined from the slope of the profile, using a least-squares fit procedure. In the investigated, core the calculated value was 0.025 g cm^{-2} a^{-1} for the last 100 years, which is a very low rate in comparison with other lakes in Poland, in which the values ranged within 0.05–0.2 g cm^{-2} a^{-1} (Tylmann, 2004; Tylmann, Białkowski, 2002). Such a low SAR value in Lake Piaseczno is connected with the high water content in sediments, which exceeded 90% along the whole dated part of the core (Fig. 5). Water content is lower only at the base of the core (55–75 cm) where sediment dry density and mass accumulation increase.

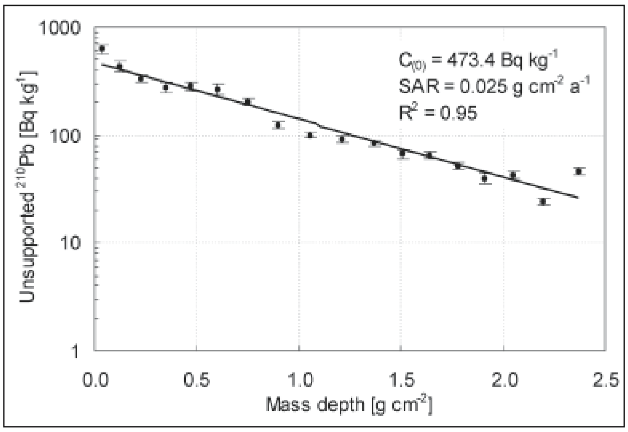


Fig. 3. Unsupported ^{210}Pb activity versus mass depth and calculated mean sediment accumulation rate (SAR)
3 pav. ^{210}Pb aktyvumo priklausomybė nuo gylio ir nuosėdų kaupimosi greičio

The AMS^{14}C date of 220 ± 30 years (Poz-16698) was obtained from the level 75–77.5 cm. Unfortunately, the calibration of such young dates is problematic because of the multimodal probability distribution caused by a plateau in the part of the calibration curve covering this time interval. In the case of the date 220 ± 30 years, three time intervals were obtained. One of them (1930–1960 AD) can be certainly excluded, but the others (1730–1810 AD and 1640–1690 AD) have a similar probability. The age–depth relation based on ^{210}Pb dates (Fig. 4) suggests that the more probable sediment age ranges within 1730–1810 AD, and this time interval was assumed for the depth of 75–77.5 cm.

Based on the relation between ^{210}Pb and radiocarbon dates, the mean SAR for the level 36–75 cm was estimated as 0.066 g cm^{-2} a^{-1}, i. e. more than twice higher than for the level 0–36 cm. This difference is connected with the decreasing water content downcore (Fig. 5). However, the calculated rate should be considered as an approximation rather than a precise value because it is based on only one radiocarbon date.

Sediment composition

The examined sediments were very loose (>90% of water content) up to the depth of 40 cm (Fig. 5). As a result, the dry density of the sediments and mass accumulation with depth were very low. A considerable variability in sediment composition was also recorded, with the exception of carbonates which were not present or showed an extremely low level (<1%). For this reason, the carbonate content is not presented in Fig. 5. The basic composition of the sediments consists of organic matter, biogenic silica and minerogenic material. There are only slight variations in biogenic silica content (5–10%), therefore, rapid and drastic changes in the lake trophy did not occur during the last ca. 200 years. In the light of water quality measurements, before 1970 the lake was oligotrophic and presently should be classified as mesotrophic. This change in its trophic status was caused by the development of recreational use of immediate surround-

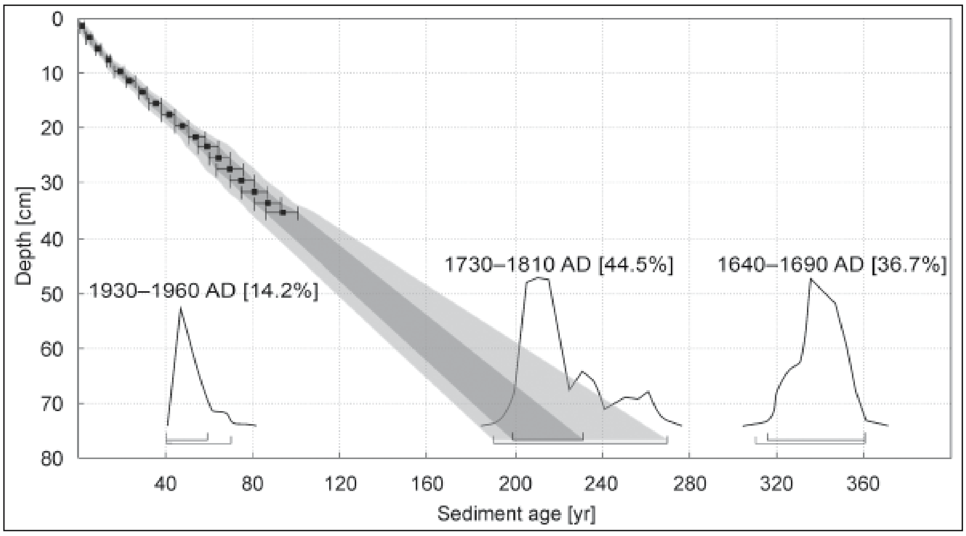


Fig. 4. Age–depth model based on ^{210}Pb dates and probability distributions of ^{14}C date (see details in the text). Dark and light grey colours present the 1σ and 2σ uncertainty range, respectively

4 pav. Amžiaus ir gylio modelis priklausomai nuo ^{210}Pb ir ^{14}C datų paplitimo

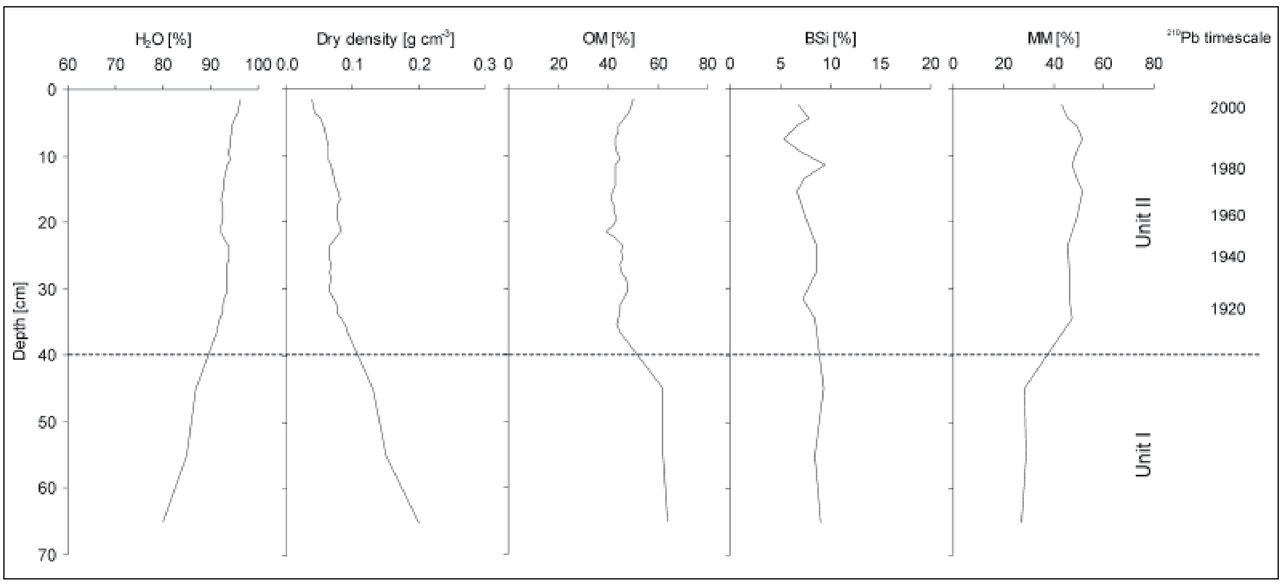


Fig. 5. Changes in the sediment composition (OM – organic matter, BSi – biogenic silica, MM – minerogenic material)

5 pav. Nuosėdų sudėties pokyčiai (OM – organinė medžiaga, BSI – biogeninis silicis, MM – mineraloginė medžiaga) ings of the lake, namely the functioning of bungalows not equipped with appropriate sewage systems.

On the other hand, organic and minerogenic matter content varies significantly along the core and allows to distinguish two units of different properties (Fig. 5). Unit I in the lower part of the core (>40 cm) is characterised by a high organic matter content (more than 60%) and a much lower minerogenic matter content (ca. 30%). In contrast, the uppermost sediments (unit II, 40–0 cm) are less organic (40–50%) and contain more of minerogenic material (up to 50%).

Such a change in sediment properties had to be caused by factors influencing the lake's functioning. Minerogenic material is of allochthonous origin, therefore it is often used as a proxy for erosion intensity in a catchment area (Dearing, 1991; Enters et al., 2008). Changes in land-use, related to agriculture development, usually increase soil erosion and thus enhance the transport of minerogenic material to the lake.

Increase in minerogenic material transport to lakes has been observed from early neolithic agriculture (Edwards, Whittington, 2001; Zolitschka et al., 2003), and most important is the deforestation of catchment areas where soil erosion from uncovered surface is much more pronounced (Einsele, Hinderer, 1997). In the case of Lake Piaseczno, a significant increase of minerogenic particle transport to the lake began in the early 20th century (Fig. 5). Analysis of archival cartographic materials from the years 1916 (Karte des Westlichen Rußlands...) and 1936 (Mapa Taktyczna Polski...) showed significant changes in land-use during that time, namely a rapid decrease in afforested areas (from 42% in 1916 to 6% in 1936). Forests were replaced by arable lands. After World War II, the western part of the catchment was afforested, and presently forests cover ca. 27% of the total area. During the sixties of the 20th century, the eastern part of the catchment was transformed from arable lands into a recreational area. At present, this type of land-use prevails in the eastern and northern surroundings of the lake (Furtak, Turczyński, 1998; Serafin, 2008; Wojciechowski, 1991; Zabiegły, 1999).

CONCLUSIONS

Radiometric dating and variability analysis of basic components in the sediments under study provided interesting results. Based on the regular distribution of ^{210}Pb, a reliable timescale was obtained for the last ca. 100 years. ^{210}Pb dates are also consistent with the radiocarbon dating of a basal sample. Changes in the minerogenic material content along the core presents an interesting record of erosion increase in the catchment area, caused probably by deforestation related to human activity. Further analyses, including palaeobiological and hydrochemical indicators, are necessary to confirm and expand our interpretations. The research is currently in progress.

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Wojciech Tylmann, Marek Turczyński, Małgorzata Kinder

SEDIMENTACIJOS AKTYVUMAS IR EROZINIAI POKYČIAI DABARTINĖSE PIASEČNO EŽERO NUOSĖDOSE (PIETRYČIŲ LENKIJA)

S a n t r a u k a

Straipsnyje pateikti Piasečno ežero paviršinių nuogulų tyrimo rezultatai. Nuosėdų amžius nustatytas ^{210}Pb izotopo metodu naudojant CF : CS modelį. Gauti duomenys buvo palyginti su nuosėdų apatinės dalies ^{14}C AMS. Pagal datavimo rezultatus apskaičiuotas nuosėdų kaupimosi greitis per pastaruosius 100 metų siekė 0,025 g/cm^{-2}/m^{-1}. Nuosėdų kaupimosi greitį žemiau ^{210}Pb diapazono nustatėme pagal ^{14}C duomenis – jis buvo 0,066 g/cm^{-2}/m^{-1}. Tyrinėti nuosėdų pagrindinių komponentų kitimo lygiai pasižymėjo silpna hidratacija ir nedideliu karbonatų kiekiu. Vis dėlto organinių ir mineralinių medžiagų kiekis rodo intensyvesnę eroziją baseine, ženkliai padidėjusią nuo XX a. pradžios. Archyvinių kartografinių duomenų analizė atskleidė, kad mineralinių medžiagų ežere padaugėjo iškirtus mišką aplink ežerą.

Войцех Тильман, Марек Турчинский, Малгожата Киндер

СКОРОСТЬ СЕДИМЕНТАЦИИ И ЭРОЗИОННЫЕ ИЗМЕНЕНИЯ В СОВРЕМЕННЫХ ОСАДКАХ ОЗЕРА ПЯСЕЧНО (ЮГО-ВОСТОЧНАЯ ПОЛЬША)

Р е з ю м е

Представлены результаты исследований поверхностных отложений ядра озера Пясечно. Возраст отложений определялся при помощи ^{210}Pb с использованием модели CF : CS. Полученные данные сравнивались с AMS^{14}C для нижней части ядра. На основании датирования рассчитаны темпы накопления осадков за последние 100 лет, они составили 0,025 г см$^{-2}$ г$^{-1}$. Темпы накопления отложений ниже диапазона ^{210}Pb установлены на основе данных ^{14}C: они составили 0,066 г см$^{-2}$ г$^{-1}$. Исследовалось также изменение уровня основных компонентов отложений. Для последних характерны очень низкая гидратация и содержание карбоната. Однако содержание органических и минеральных веществ отражает эрозионные изменения в водосборе, который существенно увеличился с начала XX века. Картографический анализ архивных материалов показал, что наиболее вероятной причиной повышения содержания минеральных веществ в озере явилась человеческая деятельность, в частности вырубка леса.