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LONG-TERM CHANGES IN 0+ FISH ASSEMBLAGES IN THE LITTORAL ZONE OF HEATED LAKES. I. DIVERSITY, EVENNES AND DYNAMIC PHASE PORTRAIT OF SPECIES STRUCTURE

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ABSTRACT. A study was conducted from 1966 to 2000 to analyze the structure and characteristics of the dynamics of differentiation in the 0+ fish assemblages in lakes with varied morphometrics, intensity, and various periods of water heating. Species domination and variation were defined by characterizing the fish assemblages. The occurrence of 24 fish species belonging to 7 families was confirmed. Changes in the composition and variety of the autochthonous ichthyofauna resulted from water heating and increased water flow. The analysis of the phase diagram trajectory indicated instability and variation in the 0+ fish assemblages of the lakes that were heated most intensely. The fish assemblage that exhibited the greatest diversity fluctuation was noted in the lake heated the most and with the most stable water exchange. However, the most diverse 0+ fish assemblage structure was noted in the lake that was least transformed and received partially cooled water only during the summer.

Key words: DIVERSITY, JUVENILE FISH ASSEMBLAGES, DYNAMIC PHASE PORTRAIT, LITTORAL, HEATED LAKES

INTRODUCTION

Since fish have a long and complex development cycle, they are one of the most sensitive components of aquatic ecosystems. Changes in water temperature impact the gonad maturation cycle, the number of eggs deposited, and further can limit the occurrence and abundance of fish (Duarte and Alcaraz 1989, Wilkońska 1992, Ahnesjo 1995). The lethal impact of water temperature varies with individual development. Juveniles are particularly sensitive to thermal changes (Blaxter 1992). Therefore, an understanding of what temporal changes occur in assemblages of juvenile fish may be key in taking applied action (Quist et al. 2004).

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Continual changes in aquatic ecosystems occur under the influence of both global factors, such as climate change (McCarty 2001), and regional ones, such as nutrient budgets (Van Der Molen and Boers 1996), hydrological conditions (Zalewski 2004), or the introduction of planktivorous fish (Kajak et al. 1975, Fukushima et al. 1999). The striking repeatability of processes that shape the structure and functioning of lakes in the temperate zone results from the long period extending from the last ice age when similar, stable external conditions prevailed over vast areas (Weiner 2003). In the face of the globalization of the climate and nature itself, lakes that have received heated waters from power plants for years might serve as models for basins with natural thermal regimes.

Studies of 0+ fish in the Konin lakes system were initiated in 1966, and focused on the impact heated discharge waters had on the reproduction, growth, diet, and fecundity of the native species (Zawisza and Backiel 1972, Wilkońska and Żuromska 1977a, Wilkońska 1994a, b, c, Wilkońska and Strelnikova 2000). Changes in the domination of juvenile fish assemblages resulting from water heating and the introduction of herbivorous fish (Wilkońska and Żuromska 1977b, Wilkońska 1988a, b) as well as the relations between the occurrence of macrophytes and the abundance and diversity of assemblages of small-sized fish were determined (Kapusta 2004).

The aim of the studies was to analyze the structure of 0+ fish assemblages and to describe the dynamics of differentiation in fish assemblages from three lakes with different morphometrics and water heating intensity and period. The hypothesis was tested that the fish assemblages in lakes with the most stable thermal and hydrological conditions are the most predictable.

MATERIALS AND METHODS

STUDY AREA

The study was performed during the 1966-2000 period in three lakes known collectively as the Konin lakes. The morphometrics and thermal regimes of these lakes differ (Socha and Zdanowski 2001). Lake Licheńskie (52°18'N, 18°20'E) is a shallow eutrophic lake that has been heated since 1958 with waters from a power plant. From 8.0 to 27.0 $m^3 s^{-1}$ of post-cooling waters are discharged, and the mean resident time of these waters is 5 days. Water temperature in the shore zone during a hot summer reaches 32°C. The lake is mixed to the bottom from early spring to late fall. The northern and southern parts of the lake, where heating is less intense, can freeze in some winters (Zdanowski 1994, Socha and Zdanowski 2001). This lake has a narrow littoral zone where the following grow: *Ceratophyllum demersum* L.; *Najas marina* L.; *Nuphar lutea* (L.) Sibth. and Sm.; *Myriophyllum spicatum* L.; *Potamogeton* sp. The small area of the shoreline shallows is overgrown with patches of *Phragmites australis* (Cav.) Trin ex Steud., *Typha* sp., and *Acorus calamus* L. In the early 1990s, the littoral zone of Lake Licheńskie was dominated by *Vallisneria spiralis* L., an alien macrophyte species in Poland (Hutorowicz 2006).

Lake Gosławskie (52°18'N, 18°20'E) is a shallow, eutrophic pond-type lake. In 1969, the water level was raised by about 1.0 m and heating began with the discharge of 6.8 to 42.9 $m^3 s^{-1}$ of post-cooling water. This lake does not freeze; the temperature of the water in the littoral zone reaches 29°C, and the mean water retention time is three to five days (Zdanowski 1994, Socha and Zdanowski 2001). Littoral zone occupies a significant area in this lake. The vegetation occurring here included *Chara* sp., *C. demersum*, *M. spicatum*, *N. lutea*, and *Potamogeton* sp. A narrow strip of rushes was comprised of *Ph. australis*, *Typha* sp., and *A. calamus*.

Lake Ślesińskie (52°23'N, 18°19'E) is a deep ribbon lake that has been heated since 1970. Partially cooled post-cooling waters are discharged into the lake from Lake Licheńskim (max. 20.0 $m^3 s^{-1}$) from May to September. Of the studied basins, Lake Ślesińskie has the longest water retention time at 14 days. The lake freezes in winter, while the temperature in the littoral zone reaches 26°C in summer. The littoral zone occupies a small part of the lake basin, and among the vegetation the dominant species are *Ph. australis*, *Typha* sp., *Potamogeton* sp., *C. demersum*, *M. spicatum*, and *N. lutea*.

The system of artificial canals that join the Konin lakes are connected to fish ponds (272 ha), Lake Gopło (2154 ha), and lowland Warta River. Fisheries commercial exploitation is conducted in all of the lakes. Three native species are the basis of commercial fisheries: roach, *Rutilus rutilus* (L.), bream, *Abramis brama* (L.), and white bream, *Abramis bjoerkna* (L.). Asian cyprinid species were introduced to the lakes in the late 1960s and early 1970s: grass carp, *Ctenopharyngodon idella* (Val.), silver carp, *Hypophthamichtys molitrix* (Val.), and bighead carp, *Aristichthys nobilis* (Richardson).

CATCHES AND DATA ANALYSIS

The fish were caught with a fry net (mesh size 1 mm) that extended through the water column from the surface to the bottom. Catches were performed in the same location in the shallow littoral zone (≤ 1 m). The fish caught during each haul were preserved in a 4% formaldyhyde solution and then identified in the laboratory under a stereomicroscope (Koblickaya 1966, Mooij 1989).

The evaluation of the structure of juvenile fish assemblages was performed based on an analysis of the dynamics of the relative abundance of individual species. The fish assemblages were characterized by determining species domination and diversity index. The evenness index was the measure of the structure and functioning of the fish assemblages (Pielou 1975). Smoothing with the weighted least squares method was used to present changes in the evenness index in the period analyzed (Statistica, StatSoft Inc.). The coefficients of equal value were compared using analysis of variance (ANOVA). Homogenity of variance was checked with the Levene's test, while the Tukey's test was used to determine which groups differed from each other.

The biodiversity of the fish assemblages was analyzed with the Shannon index, which described most integrally all of the changes occurring in the composition of the fish assemblages (Tereshchenko et al. 1994). Next, modified dynamic phase portrait were used to determine the dynamic properties of the fish assemblages (Volkenshtein 1978, Verbicky and Tereshchenko 1996). Assuming that the diversity of the fish assemblages (H') is a dynamic function of time, then the dynamic phase portrait of the fish assemblage structure is a plot that reflects changes in diversity and changes over the analyzed period (dH'/dt). The essence of the method is the analysis of the fish assemblage phase diagram trajectory within the set of coordinates x and dx/dt, where x is the parameter studied. The analysis is based on seeking stable points i.e., those with zero velocity entropy change (Tereshchenko and Strelnikov 1995). A constant state in a fish assemblage is the result of substantial resistance, the effect of forces in equilibrium, or self-regulation. This is a state that occurs rarely in nature, while slow, slight changes are interpreted erroneously as a constant state (Weiner 2003). This is why, in order to eliminate incidental changes in fish assemblages, the diversity index was smoothed by the arbitrary division of the entire observation period into 500 segments, and then approximating and interpolating the data (Verbicky and Tereshchenko 1996).

RESULTS

SPECIES COMPOSITION

The fish caught during the study belonged to 24 species representing 7 families (Table 1-3).

TABLE 1

Species composition and relative density (%) of juvenile fish in Lake Licheńskie in the 1966-2000 period

Species	1966-1969	1970-1980	1981-1990	1991-2000
Rutilus rutilus (L.)	20.95	32.91	42.76	45.83
Alburnus alburnus (L.)	11.88	31.50	33.49	39.23
Abramis bjoerkna (L.)	29.13	6.77	9.80	1.38
Scardinius erythrophthalmus (L.)	20.01	7.99	5.17	5.44
Abramis brama (L.)	4.66	10.53	1.27	6.19
Perca fluviatilis L.	3.62	2.11	3.07	0.36
Gasterosteus aculeatus L.	1.17	2.05	2.93	0.10
Leuciscus cephalus (L.)	1.50	2.78	0.97	0.36
Gymnocephalus cernuus (L.)	2.83	0.98	0.18	<0.01
Tinca tinca (L.)	1.39	0.36	0.18	0.99
Sander lucioperca (L.)	0.84	0.59	0.14	0.09
Gobio gobio (L.)	0.66	0.09	0.02	0.00
Leucaspius delineatus (Heck.)	0.13	0.57	0.00	0.00
Carassius carassius (L.)	0.23	0.03	<0.01	0.00
Cobitis taenia L.	0.23	0.01	0.01	0.00
Rhodeus amarus (Bloch)	0.14	0.05	0.00	0.00
Leuciscus idus (L.)	0.14	0.02	0.00	0.00
Anguilla anguilla (L.)	0.14	0.00	0.00	0.00
Cyprinus carpio L.	0.02	0.06	0.03	0.00
Alburnoides bipunctatus (Bloch)	0.06	0.00	0.00	0.00
Carassius gibelio (Bloch)	0.03	0.01	0.00	0.02
Esox lucius L.	<0.01	0.00	0.00	<0.01
Silurus glanis L.	0.00	0.00	0.00	<0.01
hybrids	0.24	0.61	0.02	0.00

TABLE 2

Species composition and relative density (%) of juvenile fish in Lake Gosławskie in the 1967-2000 period

Species	1967-1969	1970-1980	1981-1990	1991-2000
Rutilus rutilus (L.)	15.58	12.79	15.16	50.38
Abramis bjoerkna (L.)	17.77	17.79	51.26	5.33
Alburnus alburnus (L.)	2.95	47.89	12.06	20.56
Scardinius erythrophthalmus (L.)	56.86	12.77	3.39	2.34
Abramis brama (L.)	1.97	1.53	2.03	14.94
Leuciscus cephalus (L.)	0.02	0.75	8.12	4.25
Gasterosteus aculeatus L.	0.70	4.76	5.26	1.19
Perca fluviatilis L.	0.30	0.30	1.93	0.61
Leucaspius delineatus (Heck.)	2.49	0.01	0.00	0.00
Cobitis taenia L.	1.14	0.02	0.03	0.03
Tinca tinca (L.)	0.06	0.39	0.07	0.07
Gobio gobio (L.)	0.00	0.01	0.45	0.09
Cyprinus carpio L	0.00	0.52	0.00	0.00
Sander lucioperca (L.)	0.01	0.04	0.22	0.13
Leuciscus idus (L.)	0.02	0.31	0.00	0.00
Carassius carassius (L.)	0.03	0.08	0.00	0.00
Esox lucius L.	0.09	0.00	0.02	0.00
Carassius gibelio (Bloch)	0.00	0.00	0.00	0.07
Gymnocephalus cernuus (L.)	0.00	0.02	0.00	0.02
Pungitius pungitius (L.)	0.00	< 0.01	0.00	0.00
hybrids	0.00	0.03	0.00	0.00

TABLE 3

Species composition and relative density (%) of juvenile fish in Lake Ślesińskie in the 1966-2000 period

Species	1966-1969	1970-1980	1981-1990	1991-2000
Alburnus alburnus (L.)	24.58	29.21	35.81	62.00
Rutilus rutilus (L.)	14.85	40.00	18.65	18.49
Scardinius erythrophthalmus (L.)	4.88	11.04	9.11	3.57
Abramis bjoerkna (L.)	1.90	4.59	16.71	1.71
Perca fluviatilis L.	14.64	1.69	0.12	4.38
Rhodeus amarus (Bloch)	14.98	1.11	0.85	2.05
Leuciscus cephalus (L.)	0.00	5.58	7.91	3.37
Gasterosteus aculeatus L.	4.97	3.57	4.49	0.90
Abramis brama (L.)	1.73	1.79	5.62	2.69
Gobio gobio (L.)	9.56	0.65	0.44	0.11
Leucaspius delineatus (Heck.)	5.70	0.14	0.03	0.00
Gymnocephalus cernuus (L.)	0.76	0.09	0.10	0.49
Tinca tinca (L.)	0.69	0.12	0.03	0.22
Cobitis taenia L.	0.40	0.09	0.11	<0.01
Carassius carassius (L.)	0.29	0.01	0.00	0.00
Sander lucioperca (L.)	0.04	0.05	0.01	0.01
Esox lucius L.	0.02	0.00	0.00	0.00

The heated lake water impacted the species composition and abundance of the fish. Following the initiation of warm water discharge, the species least resistant to increased water temperature disappeared (pike, *Esox lucius* L., bitterling, *Rhodeus amarus* (Bloch), stickleback, *Gasterosteus aculeatus* L.). High fluctuations in fish abundance also indicated that water heating had a negative impact. The dominant species in the 0+ assemblage were roach, rudd, *Scardinius erythrophthalmus* (L.), bleak, *Alburnus alburnus* (L.), white bream, and bream. The increased water level and the formation of new spawning grounds and increased water temperature initially resulted in a distinct increase in the abundance of rudd (Lake Gosławskie) and predatory fish (pikeperch, *Sander lucioperca* (L.), perch, *Perca fluviatilis* L.). In the 1970's, further heating and the limitation of spawning places resulting from foraging grass carp caused a drastic decline in the abundance of phythophils fish. The appearance of "new" species in the lakes (chub, *Leuciscus cephalus* (L.), ide, *Leuciscus idus* (L.), spirlin, *Alburnoides bipunctatus* (Bloch)) was a consequence of canal construction and increased water flow. In subsequent years, changes in the species composition and abundance of fish resulted from general transformations in environmental conditions. Additional species less resistant to high water temperature disappeared (gudgeon, *Gobio gobio* (L.), perch, ide, stickleback, spirlin, ruffe, *Gymnocephalus cernuus* (L.), sunbleak, *Leucaspius delineatus* (Heck.), spiny loach, *Cobitis taenia* L.), and the increased abundance of chub and bream. In the 1990s, overall decreasing trends in both the abundance and species richness of 0+ fish assemblages were noted. The occurrence of some species (pikeperch, ruffe, bitterling) that had not occurred in the catches for years was limited to single specimens. Common cyprinids still dominated, while chub, the only one classified as dominant, became a rare species and occurred in small numbers in the lakes. The decline of chub was most intense in Lake Licheńskie (Table 1) and least so in Lake Ślesińskie (Table 3).

FISH ASSEMBLAGE STRUCTURE

The mutual connections and organization of fish assemblages in the studied lakes were different in subsequent years (Fig. 1). The structure of the 0+ fish assemblages in Lake Ślesińskie were distinctly more varied in comparison with the other lakes (ANOVA, $P < 0.0001$). During the initial period, the lowest value of the evenness index was confirmed in lakes Ślesińskie and Licheńskie. Increased evenness indexes

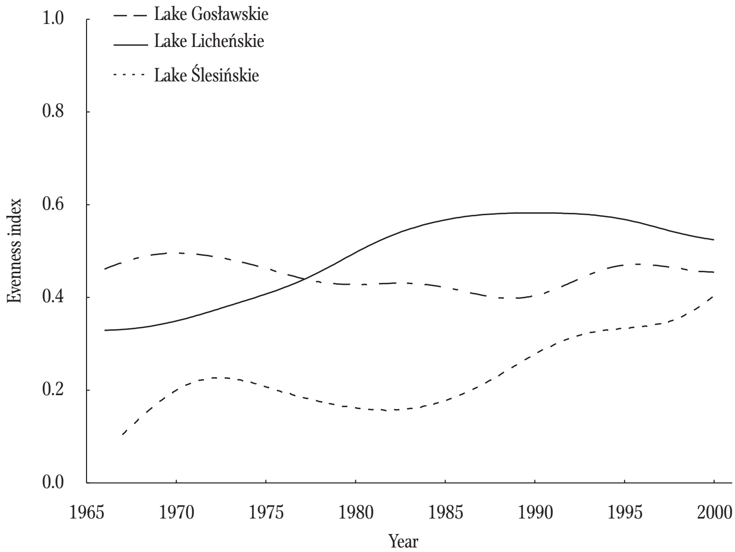

Fig. 1. Relative organization of 0+ fish assemblages in lakes Gosławskie, Licheńskie, and Ślesińskie in the 1966-2000 period. The plot was derived with the least squares method.

corresponded to the initiation of water heating in Lake Ślesińskie and indicated that elevated water temperature had a negative impact on the 0+ fish assemblages. In the second half of the 1970s, the fish assemblage structures in lakes Gosławskie and Licheńskie had similar evenness indices (0.38 and 0.39, respectively); however, distinct segregation occurred in the 1980s. While in Lake Gosławskie the value of this index increased slightly (0.46), in Lake Licheńskie it increased to 0.56. Significant changes in fish assemblage domination structure were not noted in Lake Ślesińskie until the 1990s. During this time, the organization of the 0+ fish assemblages in all the lakes was similar (Fig. 1). Only the fish assemblages occurring in lakes Licheńskie and Ślesińskie had significantly different degrees of differentiation (ANOVA, P = 0.0104, Tukey's test, P = 0.0076).

FISH ASSEMBLAGE DIVERSITY

In the first years of the study, the fish assemblages in lakes Licheńskie and Ślesińskie had the highest diversity (Fig. 2). The discharge of heated water caused declines in the diversity of the fish assemblages in all the analyzed lakes, and the greatest changes occurred in the ichthyofauna of lakes Licheńskie and Ślesińskie.

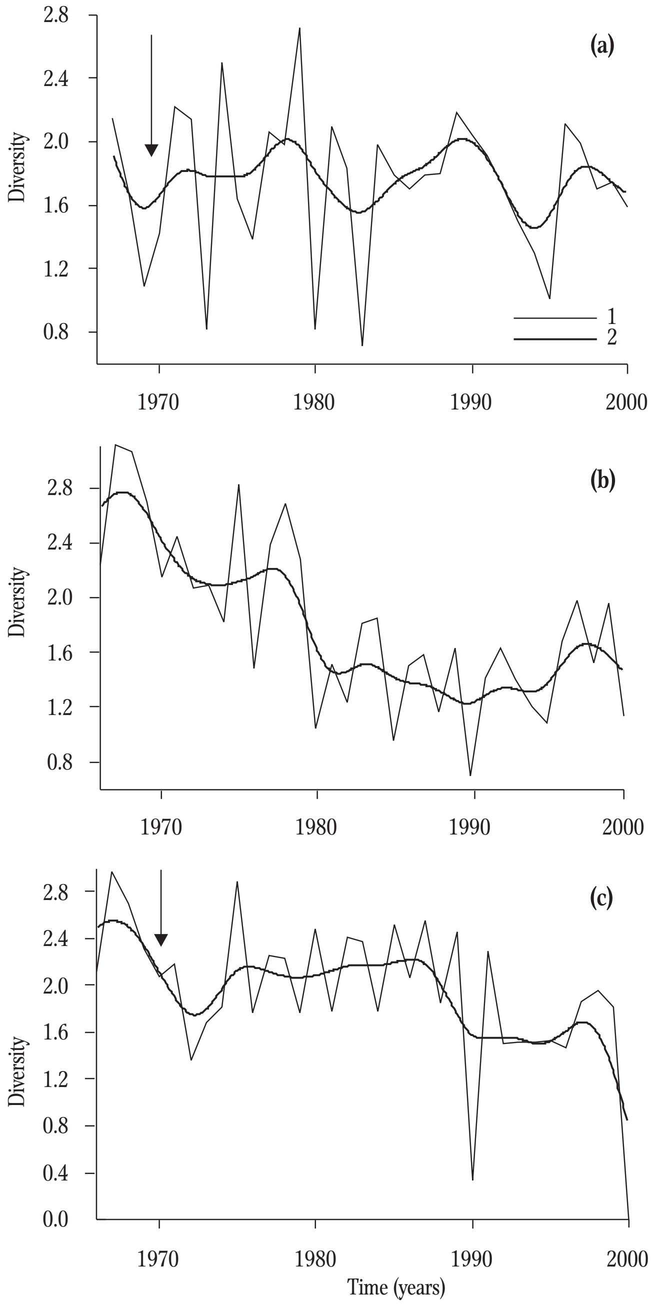

Fig. 2. Dynamics of diversity in 0+ fish assemblages in lakes Gosławskie (a), Licheńskie (b), and Ślesińskie (c) in the 1966-2000 period (1 – real data, 2 – trend line obtained with smoothing, arrow – initiation of water heating).

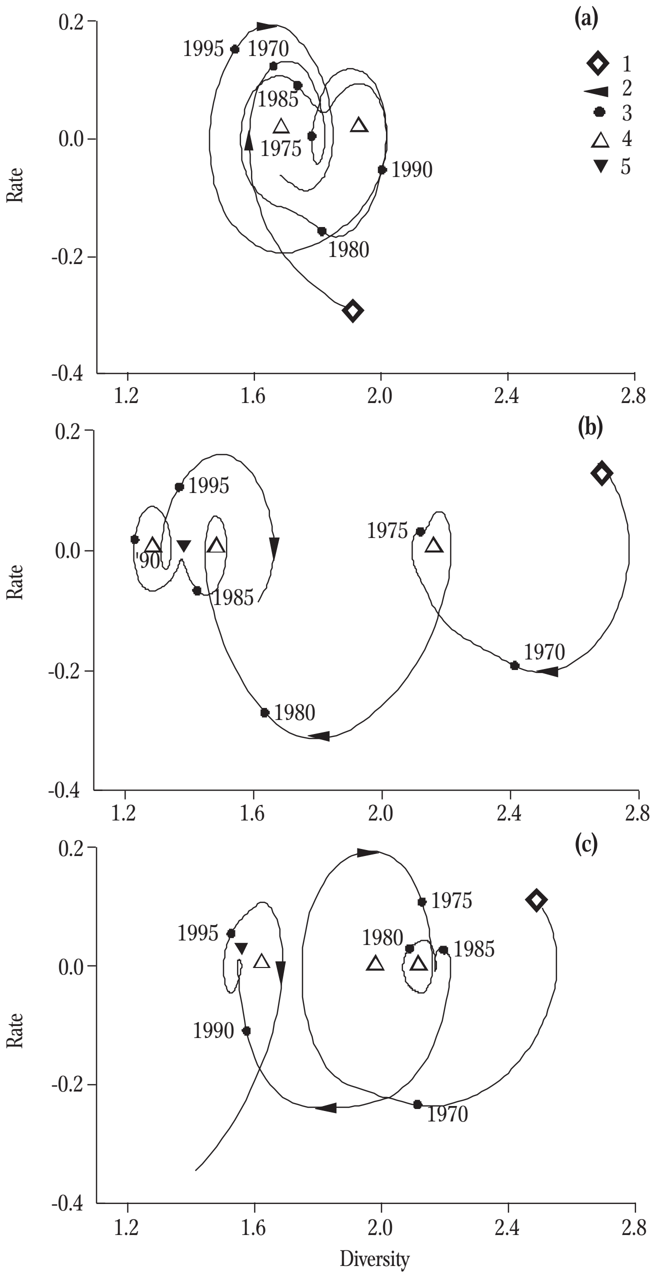

Fig. 3. Dynamic phase portrait of 0+ fish assemblages in lakes Gosławskie (a), Licheńskie (b), and Ślesińskie (c). 1 – initial state of the system, 2 – direction of changes, 3 – location of the system by year, 4 – stable position of the system, 5 – critical point of the system.

A significant decline in the diversity of fish assemblages occurred in Lake Licheńskie in 1978-1979. The analysis of the ichthyofauna differentiation dynamics on the phase diagram confirmed that there was a change in the trajectory during this period. Although at a lower level, the diversity of the fish assemblages following 1980 exhibited the highest stability (Fig. 3b). Until the end of the 1980s, juvenile fish assemblages in Lake Ślesińskie exhibited the highest stability while fluctuations in diversity were within the lowest range (Fig. 2c). In subsequent years, diversity in assemblages of juvenile fish stabilized, but at a lower level. The analysis of the dynamic phase portrait indicated that the Lake Ślesińskie fish assemblage recently underwent a drastic change (Fig. 3c). In comparison to the other basins, the greatest changes in ichthyofauna differentiation occurred in a cycle of several years in Lake Gosławskie (Fig. 2a). However, the analysis of the phase diagram for the entire study period indicated that the most predictable system and trajectory of diversity change converge at the point of equilibrium (Fig. 3a).

DISCUSSION

The results of the long-term experiments in monitoring ichthyofauna structures permit collecting information about the fundamental ecological rules that shape fish assemblages (Hall and Rudstam 1999, Gido et al. 2000, Pierce et al. 2001). The density and diversity of fish assemblages are subject to dynamic changes (Mooij 1996) and are largely dependent on the recruitment of subsequent generations and catches of adult fish (Fischer and Eckmann 1997). The degree of variability in fish assemblages depends also on physical and temporal habitat stability as well as the interactions among the species comprising the assemblage (Oberdorff et al. 2001, Olden and Jackson 2001, Lewin et al. 2004, Mehner et al. 2005). The structure and dynamics of ichthyofauna assemblages are controlled by a range of factors both abiotic, which shape physical conditions in habitats, and biotic, which characterize species behavior and morphology, as well as intraspecific and interspecific interactions (Persson et al. 1991, Holmgren and Appelberg 2000, Jackson et al. 2001, Diekmann et al. 2005). The impact hydrological and thermal conditions have on the structure of fish assemblages is well documented in marine (Brooks et al. 2002) and freshwater habitats (Hall and Rudstam 1999, Navodaru et al. 2002, Nunn et al. 2002).

The ichthyofauna of the Konin lakes is distinct in its peculiarities and is comprised of accidentally introduced species and environmental transformations that limit the occurrence of certain fish species. The habitat conditions for autochthonous fish in the analyzed lakes changed dramatically under the influence of the power plant discharge waters. As early as the first years following the initiation of heating, significant changes were noted in the structure of the fish assemblages (Wilkońska and Żuromska 1977b). Heating the lake water caused species less tolerant of high temperature to retreat and to decreases in the abundance of tench and rudd, both of which are thermophilous and stagnophilous species. The disappearance of appropriate habitats was caused by strong water currents. The occurrence in the fish assemblages of riverine species (chub, ide, spirlin) was a consequence of canal construction and increased water flow (Wilkońska and Żuromska 1977b, Wilkońska 1994c). Changes in the composition of juvenile fish assemblages was also linked to the introduction of herbivorous fish (Wilkońska 1988b) and, in recent years, the inhabitation of the lakes by stone moroko, *Pseudorasbora parva* (Temminck and Schlegel) (Kapusta unpublished data).

Over the past forty years, the Konin lakes have undergone rapid transformations related to heating, eutrophication, and water retention. Repeated attempts have been made to evaluate fully the changes observed and have included elements of aquatic physics and chemistry, the composition and abundance of plankton assemblages, and the structure and biology of the ichthyofauna (Hillbricht-Ilkowska and Zdanowski 1988a, b, Hillbricht-Ilkowska et al. 1988, Wilkońska 1989, Zdanowski 1994). Drawing a full picture of all the elements of an aquatic ecosystem is rife with challenges that stem from the necessity of introducing both generalizations and simplifications while, on the other hand, the need for formulating explicit, generally comprehensible conclusions. The problem is all the more difficult since changes occurring in aquatic environments are dynamic. There is the continual permeation and influence of biotic, abiotic, and anthropogenic factors (Jennings et al. 1999). All of these processes happen at different speeds; some are apparent quickly, such as accelerated fish growth rates (Ciepielewski 1994), while others require long-term observations to be detected (Wilkońska 1994c).

Dynamic phase portrait permit analyzing biological processes and predicting the effects of human interference in aquatic ecosystems (Verbicky and Tereshchenko 1996). Using the phase platform to analyze the diversity of 0+ fish assemblages produces a dynamic phase portrait that presents changes in diversity in graphic format.

The analysis of the Konin lake dynamic phase portrait indicated that there had been significant transformations in the fish assemblages. Heating the water resulted in the retreat of species that were less tolerant of high temperatures (Wilkońska and Żuromska 1977b) and declines in diversity (Fig. 2). These processes were the least intense in Lake Ślesińskie, the least transformed of the lakes that only received heated water during summer. Increased water temperature in the lake corresponded to declining fish assemblage diversity (Fig. 2c). However, during periods of relative stability, and even a small decline in water temperature, (Socha and Zdanowski 2001), rapid changes in ichthyofauna diversity were confirmed. It is plausible that modifications in the mutual organization of fish assemblages in Lake Ślesińskie were linked to other changes, such as anthropogenic transformations of shorelines, increasing eutrophication, and changes in the abundance of the spawning stocks due to the deployment of more efficient fishing gear.

Permanent disturbances caused by fluctuations in physical conditions or anthropogenic activities can hold a biocenosis in a state far from equilibrium (Jackson et al. 2001). The 0+ fish assemblages occurring in Lake Licheńskie, which had the highest degree of heating and the most stable water exchange, exhibited the greatest diversity fluctuations. Changes in the phase diagram trajectory indicate the system is unstable and the 0+ fish assemblages are substantially variable.

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STRESZCZENIE

DŁUGOTERMINOWE ZMIANY W ZESPOŁACH RYB 0+ W LITORALU JEZIOR PODGRZEWANYCH. I. RÓŻNORODNOŚĆ I PORTRET FAZOWY STRUKTURY GATUNKOWEJ

Celem badań przeprowadzonych w latach 1966-2000 była analiza struktury oraz charakterystyka dynamiki zróżnicowania zespołów ryb 0+ trzech jezior różniących się morfometrią, intensywnością i długością okresu podgrzewania wody. Charakterystykę zespołów ichtiofauny przeprowadzono określając strukturę dominacji oraz różnorodność gatunkową. Stwierdzono występowanie 24 gatunków ryb należących do 7 rodzin (tabele 1-3). Zmiany składu i różnorodności autochtonicznej ichtiofauny (rys. 1-2) były efektem podgrzania i wzrostu przepływu wody. Analiza trajektorii portretu fazowego wykazała małą stabilność i znaczną zmienność zespołów ryb 0+ w jeziorach najsilniej ogrzewanych (rys. 3). W jeziorze wyróżniającym się najwyższym stopniem podgrzania, a jednocześnie najbardziej stabilną wymianą wody, zespół ryb charakteryzował się największymi fluktuacjami różnorodności (rys. 3). Natomiast w jeziorze najmniej przekształconym, odbierającym częściowo schłodzone wody tylko w okresie letnim, zespoły ryb 0+ charakteryzowały się najbardziej różnorodną strukturą.