

The impact of temporal patterns of temperature and precipitation on silver Prussian carp (*Carassius gibelio*) spawning events

D. L. Bondarev*, O. M. Kunah**, M. P. Fedushko***, N. L. Gubanova****

*Dnipro-Orylskiy Nature Reserve, Obukhovka, Ukraine

**Oles Honchar Dnipro National University, Dnipro, Ukraine

***Bogdan Khmelnytsky Melitopol State Pedagogical University, Melitopol, Ukraine

****Dnipro State Agrarian and Economic University, Dnipro, Ukraine

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Dnipro-Orylskiy Nature Reserve
Obukhovka, 52030,
Dnipropetrovsk region, Ukraine.
E-mail: ihtio72log@ukr.net

Oles Honchar Dnipro National
University, Gagarin av., 72,
Dnipro, 49000, Ukraine.
E-mail: kunah_olga@ukr.net

Bogdan Khmelnytsky Melitopol
State Pedagogical University,
Hetmanska st., 20,
Melitopol, 72318, Ukraine.
E-mail: marinafedushko@gmail.com

Dnipro State Agrarian
and Economic University,
Sergey Yefremov st., 25,
Dnipro, 49600, Ukraine.
E-mail: nlg2277@mail.com

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It was revealed that Gibel carp, *Carassius gibelio* (Bloch, 1782) spawning phenology is determined by regular patterns of variability in temperature and precipitation over the period of time after spawning in the previous year. The sensitivity to temperature of water as a stimulus to spawning was shown as being dependent on the characteristics of the environment and fish development trajectories over the previous year. Information about fish spawning was collected in the Dnipro-Orylskiy Nature Reserve in the following locations: Nikolayev system of water bodies, River Protoch system and the Obukhov floodplain, the channel of the River Dnipro, water bodies of the Taromske ledge. The materials that formed the basis of this research were collected from the waters of the reserve in the years 1997–2018. There are dependencies between the air and water temperatures that have their own characteristics depending on the type of water body. These dependencies are described by a logistic equation. The temperature regime in water bodies of the Taromske ledge is very similar to the temperature regime of Nikolayev system of water bodies. The difference is that the spring period of the temperature increase in water bodies of the Taromske ledge comes earlier – in late February – early March. The air temperature dynamics over the year is described by the fourth degree polynomial. The residuals of the polynomial regression for each year were subjected to principal component analysis. The principal component analysis allowed us to identify 8 principal components of the temperature regimes, which together describe 59.2% of the variation of the residual of the polynomial trend. Deviations from the linear trend of the precipitation are systematic throughout the year, reflecting the uneven nature of rainfall during the year. The residuals of linear trend regression models of cumulative precipitation can be used as indicators of the dynamics characteristic of precipitation during the year. The residuals were used for principal component analysis, which revealed that the dynamics of the precipitation can be divided into five orthogonal principal components. The first five principal components explain 82.6% of the feature space variation. The timing of the onset of *C. gibelio* spawning in 95% of cases occurs on the 113–139th days of the year (on average, it takes place on the 125th day). Regression analysis revealed that the climate principal components and types of the lake systems can explain 79% of the variation in the timing of the onset of *C. gibelio* spawning. The water temperature at the time of *C. gibelio* spawning was exposed to natural dynamics in year aspect. The local minimum of the onset of spawning temperatures occurred in the mid 2000s. Total of 69% of the water temperature variation at which spawning begins can be described by climatic predictors and water biotope types. The variation explained by some temperature principal components may be increased considerably after including as covariates such variables as the precipitation principal component and the biotope type. This principal component which represents the high frequency variation of the air temperature regime with a characteristic period 20 and 45 days has the highest explanation ability of all the components and is a constant explanatory predictor for all considered spawning characteristics.

Keywords: spawning; temperature; precipitation; principal component analysis; phenology

Introduction

The Prussian carp, silver Prussian carp or Gibel carp, *Carassius gibelio* (Bloch, 1782) is a benthopelagic, nonmigratory (Erdogan et al., 2014), omnivorous species (Szczerbowski, 2001; Zhu et al., 2004) distributed in lentic and lotic habitats. *Carassius gibelio* is an invasive species whose populations were introduced to Europe from Asia in the 17th century and is now widely distributed in European waters (Crivelli, 1995; Vetemaa et al., 2005). Rapid increase and spread of this species have been reported in many areas including the Danube River Basin (Holčik, 1980), Southern Russia (Abramenko et al., 1997), Greece (Paschos et al., 2004), Estonia (Vetemaa et al., 2005), Turkey (Özcan, 2007), Georgia (Japoshvili et al., 2015), the Czech Republic (Luskova et al., 2010), and Eastern Ukraine (Liasko et al., 2011). Spawning takes place in shallow water (Mikheev, 2006). Sexual products mature asyn-

chronously. The silver carp spawn twice in a year in the Kuibyshev reservoir conditions (Mikheev, 2006). Three portions of eggs are formed in the silver carp female in the Dnipro-Bug wellhead system water during the growing season (Heina, 2017). It is a batch spawner (Berg, 1949), capable of producing 30 to 400 thousand eggs (Szczerbowski, 2001). In the lower courses of the Inguletz River the *C. gibelio* female absolute fecundity ranged from 79 to 477 thousand eggs. In the lower courses of the Dnipro River female fertility was in the range 200–235 thousand eggs (Bugay & Koval, 1976). The silver carp absolute fecundity ranges 39–259 thousand eggs in Dnipro-Bug wellhead system (Heina, 2017). Gibel carp is a typical phytophilous species and eggs are released on plants (Szczerbowski, 2001).

Timing of seasonal reproduction is affected mainly by changes in temperature and in hours of daylight, which is clearly illustrated by species living at high latitudes (Bone et al., 1995). The spawning time is

mainly determined by water temperature in conditions of the Kuibyshevsky reservoir. Water level regime took no effect on the spawning time. Spawning takes place from the second half of May to early July. The spawning occurs at the first portion of the daily average water temperature of at least 14 °C (Mikheev, 2006). In Turkey, spawning takes place mainly between April and June (Tarkan et al., 2007; Tarkan et al., 2012). In Greece, spawning begins at a temperature of 12–14 °C, which is observed in March–April. Fish spawning moves into deeper sites of reservoirs with continued increase in temperature of the water (Perdikaris et al., 2012). In Turkey the greatest gonadal-somatic index (GSI) for both sexes was revealed at 13 °C (Balik et al., 2004). In this region, spawning lasts from March to early May. After spawning the 4-months quiescent period takes place, and then from October to February, a rapid growth phase of the gonads occurs (Emiroğlu et al., 2012). In the conditions of Eastern Ukraine *C. gibelio* growth parameters are significantly correlated with environmental properties of the reservoirs, however, differences in the dynamics of growth of diploids and triploids have not been found (Liasko et al., 2011).

Prussian carp seem to show an extreme hypoxia-anoxia (Lushchak et al., 2001; Perdikaris et al., 2012), ammonia (Nathanailides et al., 2003) and temperature (Antonova, 2010) tolerance. It can adapt to saline water over time (Elger & Hentschel, 1981). The Prussian carp is able to reproduce from unfertilized eggs (gynogenesis) (Penaz & Kokes, 1981). The high dietary plasticity of *C. gibelio*, and its lower trophic position in the food web compared to the native fish community members was revealed. The trophic niche width of this species was larger than those of the native species (Özdilek & Jones, 2014). These properties together with gynogenesis makes it a successful invasive species (Luskova et al., 2010). Once introduced into a novel system, Gibel carp may easily become one of the dominant fish species in especially stagnant and slow-running waters (Aydın et al., 2011; Tarkan et al., 2012). Negative ecological impacts of Gibel carp to native fish communities through reproductive interference and habitat degradation have been reported from the introduced range in Europe (Paulovits et al., 1998; Hänfling et al., 2005; Gaygusuz et al., 2007). The impacts of introduced *C. gibelio* on ecosystem function are substantial (Paulovits, 1998; Slavik & Bartoš, 2004; Gaygusuz et al., 2007; Perdikaris, 2012; Tarkan et al., 2012) and could cause economic damage (Elgin et al., 2014). Direct competition for pelagic zooplankton and benthic invertebrates may reduce native cyprinid populations (Lusk, 2010). *C. gibelio* can weaken the top-down control of zooplankton except for phytoplankton by removing pelagic zooplankton resulting in turbid water (Elgin et al., 2014).

Earlier studies of fish have shown that climate change has significant relationships with species range shifts (Chu et al., 2005; Sokolov, & Zhukov, 2014; Sokolov & Zhukov, 2016), recruitment (Ficke et al., 2007; Sokolov & Zhukov, 2017), fecundity (Sundby & Nakken, 2008; Zhukov & Gubanova, 2015a), and abundance (Kallemeyn, 1987; Wingate & Secor, 2008; Zhukov & Gubanova, 2015b), but few have documented climate effects on the timing of spawning in fishes (Bondarev & Zhukov, 2017). The “match-mismatch hypothesis” assumes that the onset and duration of fish spawning and thus the temporal appearance of their larvae are relatively constant each year. The timing of the zooplankton spring bloom varies according to physical environmental conditions. When larvae appearance matches the peak of primary or secondary production, offspring survival is maximised. When larvae appearance does not match the peak abundance of their prey, the recruitment and hence the stock biomass of the next year declines (Cushing, 1990). The effect of a highly variable timing of the production peak of planktonic prey will be counteracted by the fish spreading its spawning effort over a broad temporal window (Mertz & Myers, 1994). Changes in spawning phenology could lead to the desynchronization with the plankton development and cascading effects on food chains, which may have consequences for the entire ecosystem (Blenckner, 2001; Edwards & Richardson, 2004). Deficiency of reliable long-term data on spawning fish are the cause of the much smaller number of publications on the phenology of fish compared to the phenology of birds, butterflies and terrestrial plants (McCarty, 2001; Noges & Jarvet, 2005).

Reproduction is an important biological process that controls the population dynamic and conservation of any species. Adaptation of fish

to reproduction conditions and development reflects the basic ecological conditions of the water (Kryzhanovskiy, 1949). Phenological indicators of the breeding of fish characterize the ecological status of the population and may identify the occurrence of microevolution process and completely reflect population homeostasis (Nikolsky, 1974). According to the general model, the salmon reproductive cycle is largely controlled by photoperiod duration and the carp reproductive cycle is affected by temperature (Billard et al., 1978). The temperature of the water is a crucial factor that impacts the development of fish (Brett, 1979; Herzig & Winkler, 1986; Jobling, 2003). Temperature also affects the properties associated with reproduction of fish, namely the definition of the sex, gametogenesis dynamics, gamete quality, fertility, age, sexual maturity and the duration of the reproductive period (Breton et al., 1980; Billard, 1986; Jafri, 1989; Sandström, et al., 1995; Alavi & Cosson, 2005; Lahnsteiner & Mansour, 2012; Domagała et al., 2013). Fluctuation in the timing of spawning can be an indicator of climate change (Schneider et al., 2010). Increasing temperatures due to global climate change stimulates a wound timing of spawning bream, roach but spawning occurs in the same terms as in the period to climate change (Noges & Jarvet, 2005). In spring, characterized by the most considerable changes against the background of global warming, the spawning of a great majority of fish species takes place (Noges & Jarvet, 2005). Precipitation may also act as an important factor. More frequent and more intense rainfall, which may be a result of climate change, has numerous effects such as influence on the hydrological cycle and the transportation and fate of pollutants, providing excess nutrients, increasing sediment load and eutrophication (Crozier & Hutchings, 2014). These inputs can reduce the water quality for fish and cause harmful algal blooms and the creation of hypoxic “dead zones” (NCADAC, 2013).

Most categories of seasonal activity may not begin precisely as soon as the ultimate causes reach critical levels as a relatively long duration is required for their preparation (Bondarev et al., 2018). This is particularly obvious in the case of reproduction. In many organisms developed strategies for reliable warning signals vary in strict accordance with the “ultimate” factors to regulate seasonal activity (Gwinner, 1981). These signals actually control the annual cycles of influence on physiological processes called “proximate causes” (Baker, 1938). Although ultimate factors affect the forecast annual cyclical biological processes, natural selection promotes the development of mechanisms that allow organisms to anticipate changes in environmental conditions on the basis of internal biological clock and the external opportunities to perceive warning signals (Immelmann, 1971).

Our research hypothesis is that Gibel carp spawning phenology is determined by regular patterns of variability in temperature and precipitation over a period of time after spawning in the previous year. The sensitivity to temperature of the water as a stimulus to spawning may depend on the characteristics of the environment and trajectories of fish development over the previous year.

Material and methods

Physiographic features of the Dnipro-Orylskiy Nature Reserve. In order to preserve the unique landscape of the Valley of the Middle Dnipro and the River Oril with its characteristic complex of flora and fauna the Dnipro-Orylskiy Nature Reserve was created in 1990. Today it is the only strict nature reserve (zapovednik) in Dnipropetrovsk region of Ukraine. The reserve protects the landscapes and the biodiversity of the valley of the Dnipro and its tributary the River Oril. The total area of the reserve is 3,766 hectares, and about 30% of it is covered by water, most of which is unique floodplain lakes (Bondarev & Zhukov, 2017).

The reserve is located on the upper area of the Dnipro reservoir, which has suffered considerable anthropogenic transformation (Sharamok et al., 2017). This has created the need for comprehensive ichthyological research to determine the direction and depth of the processes that occur in populations of fish influenced by the actions of the aggregate anthropogenic factors (Bondarev, 2007). Research on the fish fauna of the reserve enables us not only to identify the composition of the fish fauna and the character of its distribution in the water bodies but also to reveal the direction of the processes that are taking place in the

ecosystem in general (Bondarev, 2007). Information about fish spawning was collected in the following locations (Fig. 1).

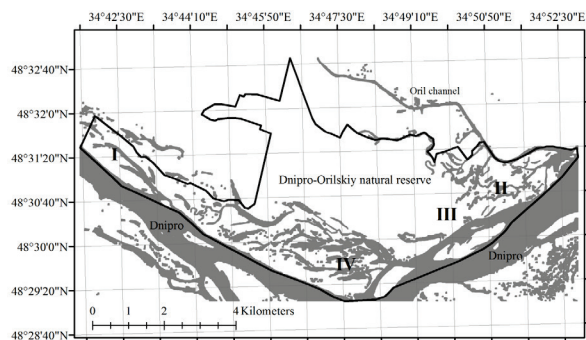


Fig. 1. Map of the Dnipro-Orylskiy Nature Reserve and spawning locations: I – Nikolayev system of water bodies; II – River Protoch system and Obukhov floodplain; III – the channel of the River Dnipro; IV – water bodies of the Taromske ledge

Nikolayev system of water bodies. The system of flood waters, located in the narrowest part of the floodplain terraces. The water bodies extend in a narrow strip extending along the flow of the Dnipro. The maximum distance from the Dnipro within this part of the reserve is about 300–1,000 meters. It is characterized by high level of flow and drop in the water level during the day, depending on the operating conditions of the reservoir. Part of the water body, connected with individual channels of the specified area, is located outside the reserve. Shallow areas (littoral zone) are minimal. Maximum depth is 5.6 meters. In recent years, the water in the central part of this area has been actively silted up with sandy sediment due to the accumulation of excess sandy deposition in areas outside the reserve and the formation of new sand spits and islands.

River Protoch system and Obukhov floodplain. Most of the ponds are poorly flowing, shallow waters which are remnants of the lower parts of the Protoch creek which united the Dnipro with the old course of the Orel. The ponds were flooded due to the formation of the reservoir. The water regime of the Protoch system and the Obukhov floodplain is under significant influence of the water regime of the reservoir. The water bodies are characterized by significant silting (in some places the thickness of silt accumulation reaches 0.6–1.0 m) and growth of aquatic embryophytes. The system is connected with the Dnipro and the mouth of the Orel by narrow streams. The greatest distance between the Dnipro and the Orel within this section is about 2 km.

The channel of the Dnipro. Includes the area of the upper Dnipro reservoir, which partially retains a river regime. The area studied is along the left bank between Krachynny and Kamyaniy islands. Biotopes are characterized by high level of change in water levels and moving sand masses associated with active formation of channel processes at the site of the reservoir. Depths range between 2–7 meters. Between these islands a part of the rock ridge is located, stretching from the right bank of the Dnipro to the left bank.

Water bodies of the Taromske ledge. The system of flood waters, located in the lowest part of the floodplain terraces is a unique floodplain biogeocoenosis in the steppe Dnipro region. According to Pervukhin's (1979) genetic classification, it is an example of the oxbow lakes formed in the Dnipro floodplain. All lakes are separated from the Dnipro bed by a belt of sand and connected by multiple channels, directly related to the channel of the Dnipro. Most ponds have a significant littoral zone that is intensely covered with aquatic embryophytes. Depths range between 1–10 meters. Water exchange is carried out through the operation of the reservoir and spring floods. Maximum distance of these ponds from the Dnipro river is about two kilometers. At present, the ponds of the specified area are being actively swamped and silted due to unbalanced operation of the reservoir. In some parts the thickness of silt reaches 0.3–0.7 meters.

Methods of researching spawning phenology. The materials that formed the basis of this research were collected from the waters of the reserve in the years 1997–2018. Sampling was conducted using a standard set of fishing gear (nets with mesh size 30–90 mm) in different

parts of the waters of the reserve. All work associated with the removal of fish from natural water bodies was conducted in accordance with the current norms and regulations using standard ichthyological methods (Chugunova, 1952; Pravdin, 1966; Arsan et al., 2006).

During the research we conducted full or partial biological analysis of the fish. We determined the species, size, weight, gender, stage of maturity of sexual products, and selected samples to determine the age and fertility. Determining the stage of maturity of sexual products actually allowed us to track phenological dates of the beginning of spawning of some fish species. All data was recorded in a special journal. Additionally, tracking of weather conditions, fluctuations in water level and water temperature were determined.

In addition, to obtain data on the characteristics and intensity of fish spawning we made visual observation and conducted planned survey routes through the spawning grounds with stops every 20, 50, 100 m to check the vegetation and presence of fish eggs. If roe was found, the place of its location was described in detail. We noted the name of the water body, depth, water temperature, time of day, type of vegetation and richness of the spawning (Koblitskaya, 1963).

Assessment of spawning events. The period of spawning (beginning and end) was estimated by the usual calendar. According to astronomical solar calendar, dates were converted into variables that represent the number of days from January 1 of each year to the spawning event (beginning and end).

Meteorological data. We used the data from the meteorological observatory of the city Dnipro. The water temperature measurement was conducted at the time of the start of spawning in the water body. Measurement of water temperature was conducted in the 12–13th hours of the day. The water temperature data were correlated with information about average air temperature according to the Dnipro weather station. Dependencies were observed between the air and water temperatures that have their own characteristics depending on the type of water body. These dependencies are described by a logistic equation of the form:

$$Y = \frac{A}{1 + \exp(b * (x - C))},$$

where Y is the water temperature, x is the air temperature, A , b , C are regression coefficients. The seasonal course of temperature in each water body for the first half of each year of research was extrapolated based on the regression.

Results

Dependencies between the air and water temperatures. There are dependencies between the air and water temperatures that have their own characteristics, depending on the type of water body (Fig. 2). The pattern of the water temperatures course in the first half of the year has a characteristic form. The specific of each water body was estimated as the residuals of a regression model with trend variability of temperature during the first half of the year as predictor. For ponds within the Nikolayev system of water bodies a characteristic sharp rise in temperatures was observed in the period from the second half of March till the second half of April (Fig. 2, I). The ponds within the River Protoch system and Obukhov floodplain are characterized by slow temperature increase in comparison with the general trend in the spring (Fig. 2, II). The highly variable nature of temperature regime also must be noted, which makes it difficult to select the sustainable patterns. It is clear that the natural variability of hydrological regime of these water bodies is complicated by the Orilsky channel, which is of anthropogenic origin. A slow warming of water in the early spring, which is reflected as a significant negative deviation from the overall trend, is revealed in the channel of the River Dnipro (Fig. 2, III). Starting from the second half of April, the intense warming of water in the Dnipro River begins and in the summer the water in the river is warmer than in the lakes. The water in the lake system is cooler probably due to colder groundwater recharge and relatively larger water surface that is covered with vegetation. Plants create a larger surface area through which water evaporation and heat transfer take place.

The temperature regime in the water bodies of the Taromske ledge is very similar to the temperature regime of the Nikolayev system of

water bodies (Fig. 2, IV). The difference is that the spring period of the temperature increase in the water bodies of the Taromske ledge comes earlier – in late February – early March.

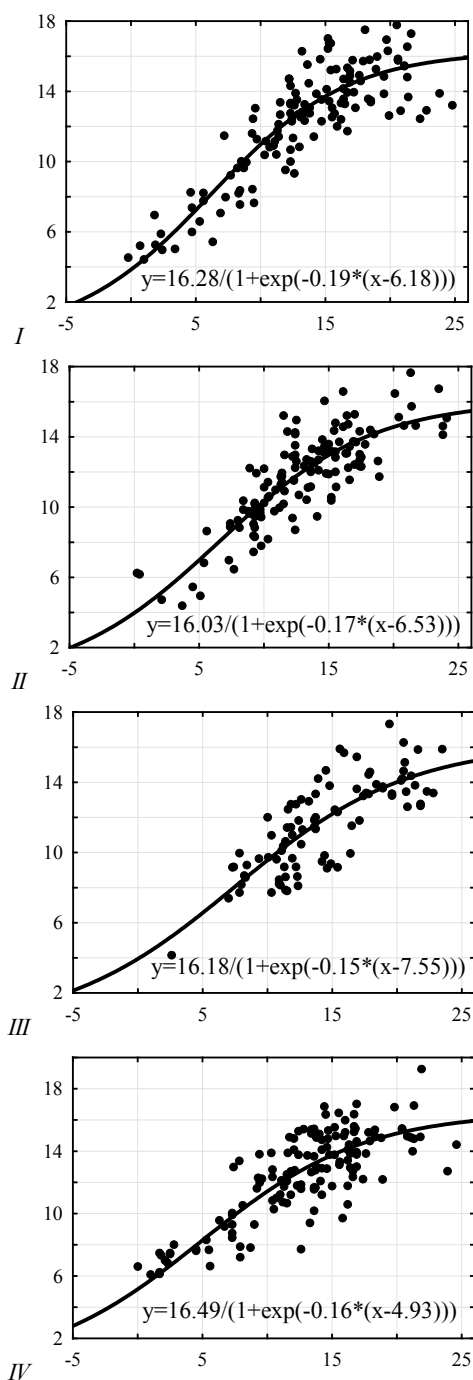


Fig. 2. The dependence of water temperature in the water bodies (y-axis, °C) of the average daily air temperature according to the weather station (x-axis, °C): I – Nikolayev system of water bodies; II – River Protoch system and Obukhov floodplain; III – the channel of the River Dnipro; IV – water bodies of the Taromske ledge

The cluster analysis of the temperature patterns showed that the Nikolayev system of water bodies is similar to the water bodies of the Taromske ledge and in turn the channel of the River Dnipro is similar to the ponds within the River Protoch system and the Obukhov floodplain (Fig. 3a). The modal values of temperatures are closest between the Nikolayev system of water bodies and the ponds within the River Protoch system and the Obukhov floodplain. The River Dnipro is considerably different in medium temperature indicators from the lake systems (Fig. 3b). According to this indicator, the water bodies of the Taromske ledge are somewhere in between the River Dnipro and the other lake systems.

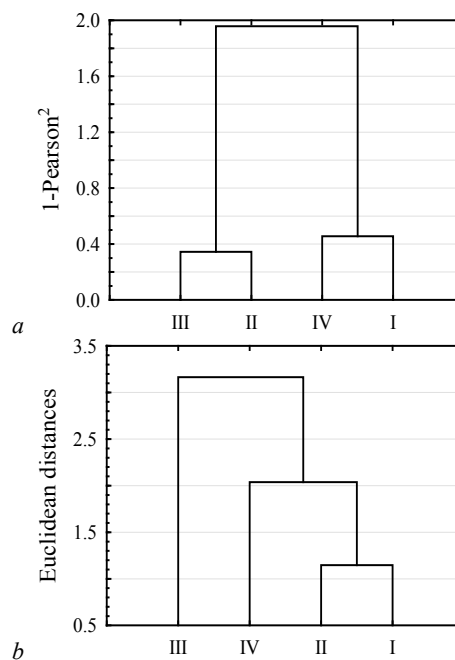


Fig. 3. Cluster analysis of the similarity of temperature regimes of the water bodies of the Dneprovsko-Orelysky Nature Reserve: I – Nikolayev system of water bodies; II – River Protoch system and Obukhov floodplain; III – the channel of the River Dnipro; IV – water bodies of the Taromske ledge; Ward's method of Pearson distance (a) and the Euclidean distance (b)

Air temperature temporal patterns. The air temperature dynamics over the year is described by fourth degree polynomials (Fig. 4). The residuals of the polynomial regression for each year were subjected to principal component analysis.

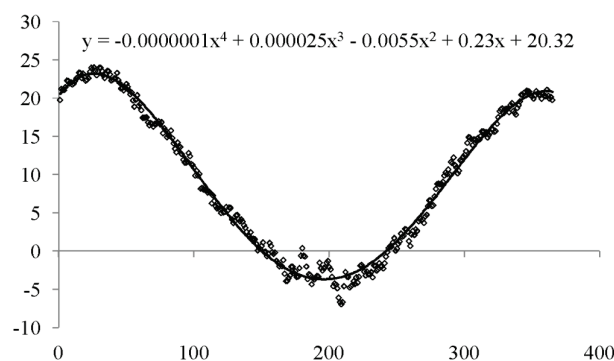


Fig. 4. The trend of temperature variability from July 1 of the preceding year to June 31 over the period 1997–2018: the dots indicate the average daily averaged data on temperature, the line – the trend of the fourth order polynomial; the horizontal axis – the order of days from 1 July; ordinate – temperature, °C

The principal component analysis allowed us to identify 8 principal components of the temperature regimes, which together describe the 59.2% variation of residual of the polynomial trend (Table 1).

The correlation coefficients indicate the degree of manifestation of a particular aspect of the temperature data variation. They can be used as predictors for describing indicators of fish spawning. The values of the principal components can be used to interpret them (Fig. 5). The principal component 1 indicates a sharp temperature drop in January. Warming in late December – early January, replaced by a sharp drop in temperature in the remaining part of January. Negative values of the principal component 1 are opposite to the points with interruption of the cold during the winter - sudden warming in January. This principal component explains 12.8% of the variability in temperature trend residuals, indicating that it is a very important part of this pattern in the temperature regime of the region.

Table 1
Principal component analysis of temperature regimes variation (only statistically significant correlation coefficients are presented at $P < 0.05$)

Variables	Principal components							
	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8
1998	0.32	–	–	–0.13	–	–	–0.22	–
1999	–0.13	–	–	0.11	–	–	–	–0.11
2000	–	–0.14	–0.11	–0.11	–	–	0.15	–
2001	0.25	–	–	–	0.19	–0.13	–	0.12
2002	–0.26	–	–0.13	–	–	–	–	–
2003	–	–0.23	–	–	–	–	–	–0.20
2004	–	–	–	–	–	–0.15	0.13	–
2005	0.40	–0.32	–0.14	0.37	0.22	–	0.27	–0.46
2006	0.61	0.32	–0.12	–0.15	–0.11	–0.24	0.24	–
2007	–	–0.52	0.27	0.20	–0.42	–	0.29	0.43
2008	–0.46	–	–	–	–0.19	–0.63	0.42	–
2009	–0.46	–0.13	–	–0.49	–0.35	–	–	–0.29
2010	0.58	0.20	–0.20	–0.48	–0.24	–	–0.15	–0.15
2011	0.24	–0.16	0.70	–0.35	–	–0.21	–	–
2012	0.65	–0.15	–	0.25	–	–0.32	–	–
2013	–	–0.61	–0.36	–0.24	–	–	–0.42	–
2014	0.45	–	0.54	–	–0.37	0.29	–	–
2015	–0.39	0.23	0.54	–	0.39	–0.19	–0.25	–0.21
2016	–	0.28	–	–0.47	0.41	0.26	0.41	0.29
2017	0.17	0.49	–	0.27	–0.21	–0.32	–0.34	0.35
2018	0.35	–0.41	0.14	–0.28	0.45	–0.29	–	0.28
Statistics								
Eigenvalue	2.68	1.68	1.63	1.52	1.40	1.24	1.18	1.11
Total %	12.76	8.00	7.74	7.24	6.67	5.93	5.61	5.28
Cumulative eigenvalue	2.68	4.36	5.99	7.51	8.91	10.15	11.33	12.44
Cumulative variation	12.76	20.76	28.51	35.74	42.41	48.34	53.95	59.22
Characteristics periods (days)	40–60	18, 24–33	24–26, 30–36	21–22, 28–36	19–36, 45, 72	20, 45	30, 40	26–28, 45, 91

The principal component 2 explains 8.0% of the variability in the data set. This component reflects the pattern of sharp temperature drop

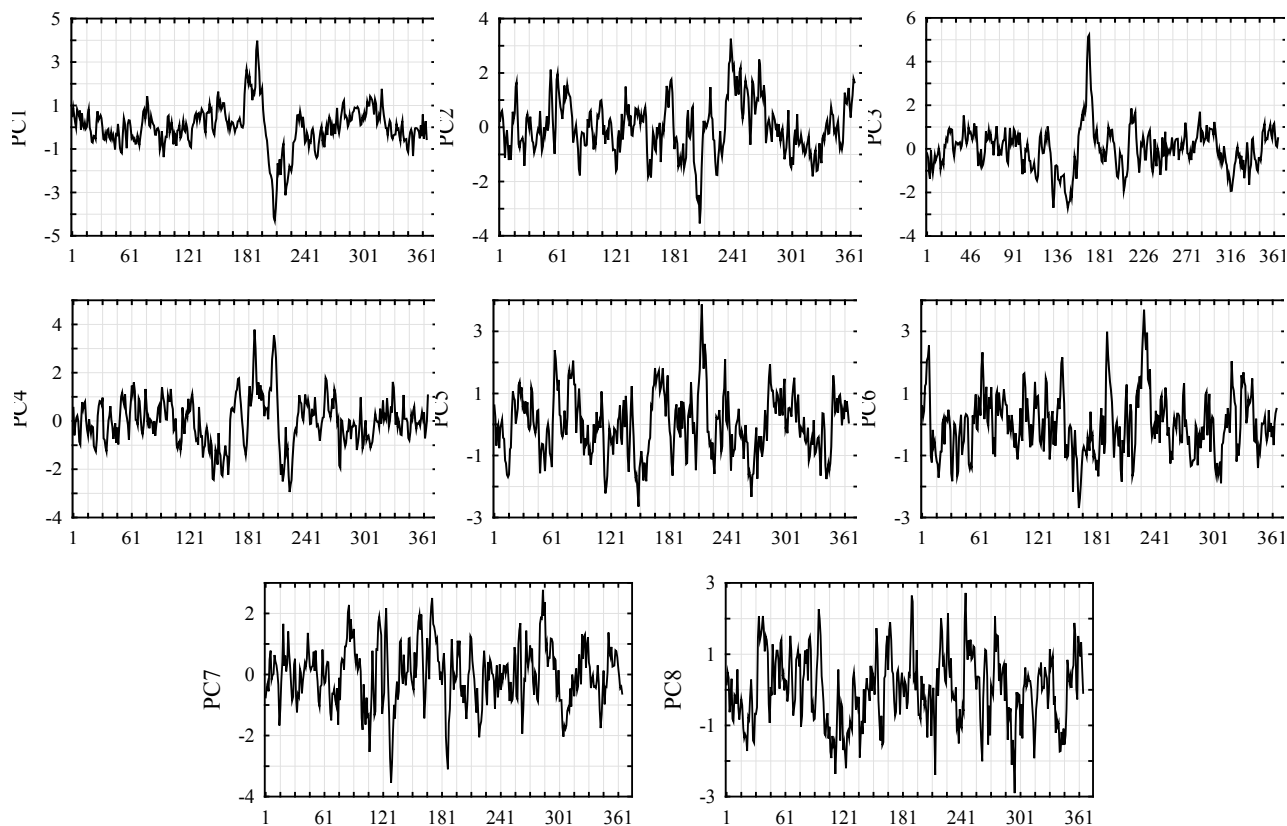


Fig. 5. The temporal patterns of the temperature principal component 1–8: the axis of abscissa is the order of the day since 1 July of the previous year; the axis of ordinate is the scores of the principal components 1–8

at the end of January – the second half of February. Positive values of this principal component indicate a cold snap at the end of January, which was replaced by warming in the second half of February. Accordingly, the principal component of the opposite sign indicates warming in January, which was replaced by cooling in January. The principal component 3 explains 7.7% of the variability of the feature space. This principal component indicates the temperature spike in mid-December. When the values of this principal component were positive, a sharp short-term warming took place, while negative – a sharp short-term cooling occurred during the above-mentioned period. The principal component 4 explains 7.2% of the variability of the feature space. This principal component refers to a tendency to a sharp increase in temperature during the second half of December – the second half of January. The elevated temperature state is extremely unstable. This period is preceded and terminated by periods of dramatically reduced temperature. The principal component 5 explains 6.7% of the variability of the feature space. The general nature of the temperature course, which this principal component reflects, is a factor similar to the previous, but with a phase shift at a somewhat later stage. The characteristic temperature spike was observed from the beginning of January until the second half of January. Also this surge is limited to the periods of reduced temperature before and after it. The principal component 6 explains 5.9% of the variability of the feature space. This principal component refers to the cold snap in early December and a warming trend until the middle of February, after which there was a trend of cooling to the end of April compared to the overall long-term trend of seasonal temperature changes. The principal component 7 explains 5.6% of the variability of the feature space. This principal component describes a tendency of a sharp decline in temperature from late March to early May, after which the temperature increase takes place. The principal component 8 explains 5.3% of the variability of the feature space. This principal component reflects the presence of sharp changes in temperature lasting 2–4 weeks, which follow each other sequentially during January–May of each year.

Thus, the winter period shows the highest degree of deviation from the seasonal course of temperatures. During winter there are always periods of abrupt cooling and warming of air temperatures. The first 4–5 principal components indicate the most common time of such phenomena. As a rule, the period of excess high (low) temperature is combined with reverse temperature spikes, which preceded or followed them. The principal components 5–8 reflect high-frequency oscillatory processes. Typically, this consists of 2–3 week periods of uplift-decrease in temperatures related to the annual average trend. The features of the principal components 5–8 are in phase shift oscillating processes. The combination of formally independent periodic processes described by the principal components, creates a specific regime of the course of temperatures which is characteristic for each year. The specificity lies in the general nature of the warming during the spring when spawning events occur (warm-cold spring). Also special reproducible (periodical) regimes are presented by the short-term periods of rising and falling temperatures in comparison with the annual average trend.

All principal components are characterized as stationary for the period of research in the sense that there is no meaningful trend of the variability during the specified time. The exception is the principal component 8, which is characterized by a high linear correlation over time ($r = 0.41$, $P = 0.07$).

Precipitation dynamic. Rain falls unevenly throughout the year (Fig. 6a, b). During the year, the number of days without precipitation varied 223 to 321 (median – 295). Thus, the data series on precipitation are not a continuous variable. The upper limit of cumulative precipitation is a smooth line, which can be approximated by the equation:

$$Y = 1.09 \cdot x,$$

where Y – cumulative precipitation, x – the order of days from July 1 of the previous year (Fig. 6c). The linear trend involves the implementation of the hypothesis of a uniform precipitation throughout the year. Deviations from the linear trend are systematic throughout the year, reflecting the uneven nature of rainfall during the year (Fig. 6d). The residuals of linear trend regression models of cumulative precipitation can be used as indicators of the dynamics characteristic of precipitation during the year. The residuals were used for principal component analysis, which revealed that the dynamics of the precipitation can be divided into five orthogonal principal components. The first five principal components explain 82.6% of the feature space variation (Table 2).

Table 2
Principal components analysis of the precipitation variation

Variables (the deviations from the trend within one year)	Principal component				
	PC1	PC2	PC3	PC4	PC5
1998	-0.90	–	-0.12	-0.22	-0.11
1999	0.93	0.17	–	–	-0.19
2000	0.27	0.49	0.24	-0.57	0.35
2001	0.67	-0.27	0.50	–	-0.14
2002	-0.63	-0.11	-0.69	–	–
2003	-0.71	–	0.59	–	–
2004	0.77	0.42	–	–	0.20
2005	-0.62	0.36	0.48	-0.30	0.10
2006	0.31	0.79	-0.25	0.11	0.24
2007	-0.50	0.53	0.38	–	-0.21
2008	-0.64	-0.34	-0.28	-0.28	-0.42
2009	-0.41	0.66	0.38	0.13	–
2010	-0.23	0.81	-0.27	0.27	0.11
2011	–	0.64	-0.32	0.45	–
2012	0.80	0.39	-0.11	-0.16	-0.12
2013	-0.75	0.45	-0.28	0.15	–
2014	0.14	–	0.41	0.76	-0.14
2015	0.48	0.37	0.12	–	-0.69
2016	0.91	-0.13	–	–	0.19
2017	0.30	-0.53	-0.13	0.33	–
2018	0.38	0.63	-0.26	-0.24	-0.49
Eigenvalue	7.59	4.38	2.37	1.67	1.34
Total %	36.14	20.87	11.27	7.97	6.37
Cumulative eigenvalue	7.59	11.97	14.34	16.01	17.35
Cumulative variation	36.14	57.02	68.29	76.25	82.62
Characteristic periods	–	182	182	121	91–182

The correlation coefficients of the original variables (rows of the deviations within one year) and principal components indicate the de-

gree of corresponding trend expression during a given year (Table 2). The trend character can be tracked by time dynamics of principal components scores (Fig. 7). The principal component 1 explains 36.1% of the feature space variation. It reflects a downward trend in rainfall from late summer until the end of December and a further increase in rainfall until the end of June. Accordingly, the negative value of the principal component 1 indicates a reverse trend. The principal component 2 explains 20.9% of the variability in the data set. This component indicates a local maximum rainfall in March and April, and local minima of precipitation in November and the first half of January. The principal component 3 explains 11.3% of the variability of the feature space. It reflects the existence of a rainfall local maximum in autumn and a local minimum in December and January. The principal component 4 explains 8.0% of the variation of the feature space. It reflects vibrational changes in the intensity of precipitation with a period of about 120 days, amplitude of which decays after the end of April. The principal component 5 indicates three local precipitation maxima. The first local maximum is characteristic of the second half of August and September, the second local maximum – for January and February, and the third – for the end of May and June. The peculiarity of this component is that it reflects a trend of increasing rainfall throughout spring.

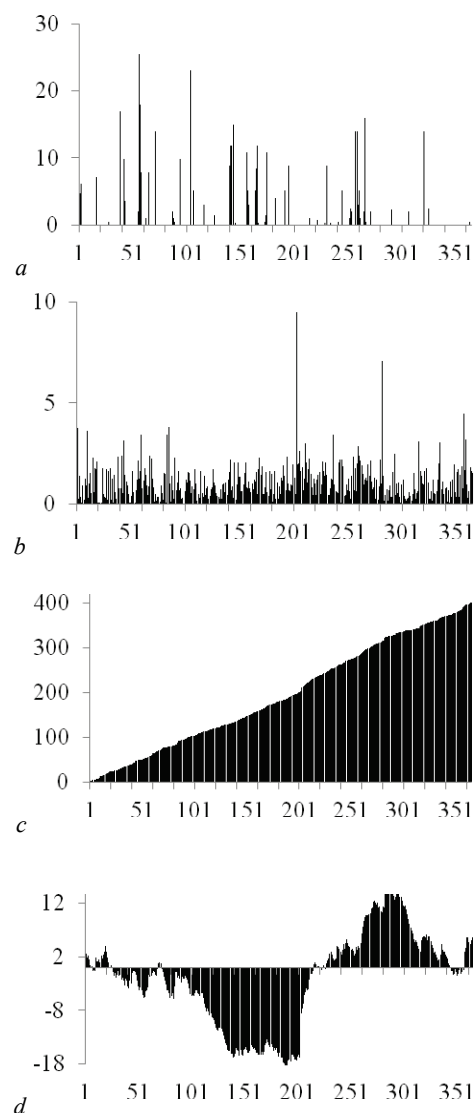


Fig. 6. Dynamics of precipitation throughout the year: a – 1998, b – averaged data for the period 1998–2018, c – cumulative rainfall average for the period of research (upper boundary is approximated by the equation $Y = 1.0845 \cdot x$, where Y is the cumulative precipitation, x is the order of the day, starting from 1 July of the previous year), d – deviations from trend equation cumulative rainfall average for

the period of studies; the x-axis is the order of the days from 1 July of the previous year to 30 June of the year line; y-axis – precipitation, mm

Spawning characteristics. The timing of the onset of *C. gibelio* spawning in 95% of cases occurs on the 113–139th days of the year (on average, it takes place on the 125th day) (Table 3). The spawning began earlier during the period of research as evidenced by a statistically significant negative correlation coefficient between the onset time of spawning and the year serial number ($r = -0.24$, $p = 0.03$). The distribution of the spawning onset time is a left-skewed asymmetric (Fig. 8). A distribution with statistically significant negative kurtosis indicates the priority of spawning at an earlier date.

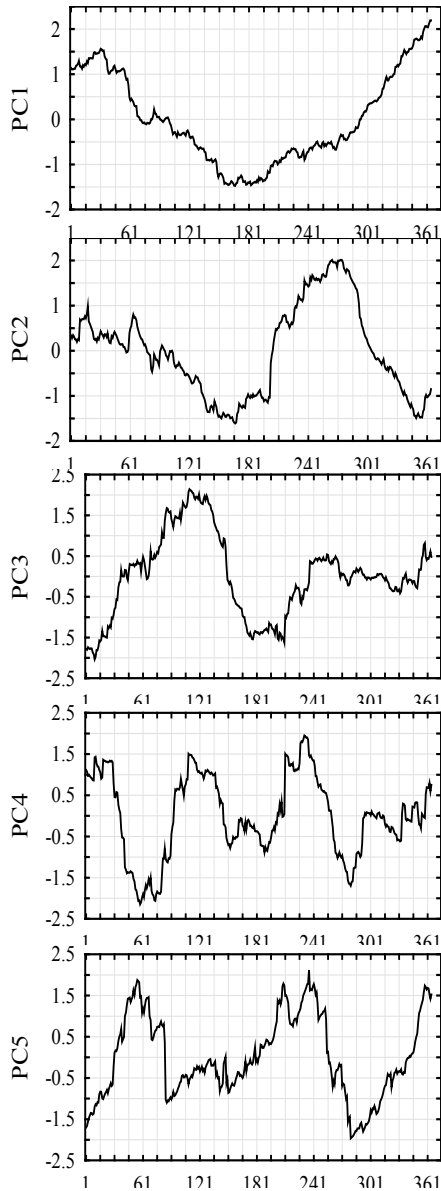


Fig. 7. The temporal patterns of the precipitation principal components 1–5 variation: the horizontal axis – the order of the day from 1 July of the previous year; y-axis – the principal components PC 1–5 scores

The timing of the end of spawning in 95% of cases occurred on the 134–160th days of the year. The end of spawning also tended to shift to an earlier period during the study period ($r = -0.25$, $P = 0.02$). Distribution of end of spawning data is symmetric and without significant kurtosis. Spawning duration occurs in 95% of cases in 9–33 days. Duration of spawning was nonlinear during the study period (Fig. 9a). The local minimum of the spawning duration was observed in 2004–2008. The distribution of the spawning duration is symmetrical and without kurtosis.

The onset of *C. gibelio* spawning in 95% of cases occurred at water temperature of 11.5–15.5 °C. This parameter of the spawning is subject to

a non-linear trend in time with a local minimum in the period of 2008–2010 (Fig. 9b). The cumulative temperature for spawning in 95% of cases was in the range 165.6–361.4 °C. This parameter varied nonlinearly over the study period. Its minimum is found in the period of 2006–2009.

Regression analysis revealed that the climate principal components and types of the lake systems can explain 79% of the variation in the timing of the onset of *C. gibelio* spawning (Table 4). The temperature principal components 1, 2, 5, and 6 are characterized by the statistically significant regression coefficients.

Table 3

Descriptive statistics of *Carassius gibelio* spawning characteristics for the period 1997–2018 (N = 84)

Characteristics	Mean ±SE	Percentile		Asymmetry ±SE	Kurtosis ±SE
		2.5%	97.5%		
Onset of spawning (days of the year)	125.58 ± 1.07	113.0	139.0	0.36 ± 0.26	-0.94 ± 0.52
End of spawning (days of the year)	146.87 ± 0.86	134.0	160.0	0.20 ± 0.26	-0.54 ± 0.52
Duration of spawning (days)	21.29 ± 0.78	9.0	33.0	0.16 ± 0.26	-0.06 ± 0.52
Water temperature at start of spawning (°C)	13.51 ± 0.13	11.5	15.5	0.16 ± 0.26	-0.23 ± 0.52
Cumulative water temperature during of spawning (°C)	252.10 ± 6.45	165.6	361.4	0.09 ± 0.26	-0.96 ± 0.52

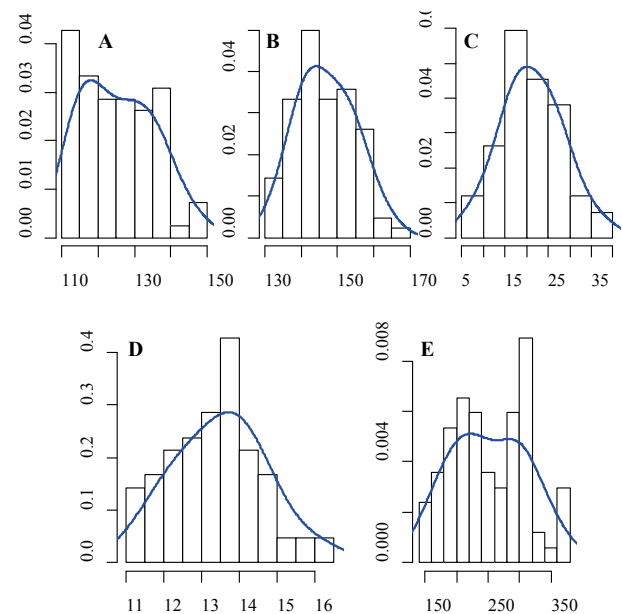


Fig. 8. Histogram *Carassius gibelio* distribution of the onset of spawning (A, x-axis – days of the year), end of spawning (B, x-axis – days of the year), spawning duration (C, in days), the water temperature at the time of the spawning start (D, x-axis – °C), cumulative water temperature during spawning (E, x-axis – °C). Y-axis – distribution density

All of these principal components showed monotonous dynamics during the period before spawning (Fig. 10). The differences between these components are in the different durations of this period. The principal components 1 and 2 have the most extensive monotonous periods before onset of spawning. The principal component 5 has the shorter monotonous period and the principal component 6 has the lowest duration of the monotonous period. Common to all principal components is that the increasing trend of temperatures that marked each of these monotonous dynamics periods contributes to the earlier onset of *C. gibelio* spawning. The converse is also true: in the year of the downward temperature trend, the start time of *C. gibelio* spawning is postponed to a later period. The observed spawning start time is dependent on the degree of convergence focus of temperature trends that marked each of the principal components. Account should be taken of the fact that according to the mathematical nature, the principal components are orthogonal, i.e. independent variables. The combination of this year positive dynamics of the principal components 1, 2, 5 and 6 leads to the earliest *C. gibelio* spawning. Such an

event can be qualitatively described as early springtime rapid warming. A combination of negative dynamics of these factors corresponds to late spring in the year of which *C. gibelio* spawning will begin late.

The principal components of precipitation variation 2 and 5 are statistically significant predictors of *C. gibelio* spawning time. There has been a downward trend in precipitation in the period before spawning which was marked by both principal components. The difference between principal components consists in the duration of this period. For the principal component 5, duration of this period is longer than for the principal component 2. Positive signs of regression coefficients indicate that the above trends contribute to an increase in the spawning timing. In other words, the lack of precipitation in period before spawning increases the timing of the onset of *C. gibelio* spawning. The principal component 2 indicates that the period of low precipitation, which begins 20 days before the earliest date of *C. gibelio* spawning, can push back the start of the spawning. The principal component 5 indicates that the decline in rainfall patterns in the period from 60 days before the start of spawning moves the start of spawning to a later period. Thus, rapid springtime warming in combination with an increased amount of precipitation promote an earlier period of *C. gibelio* spawning.

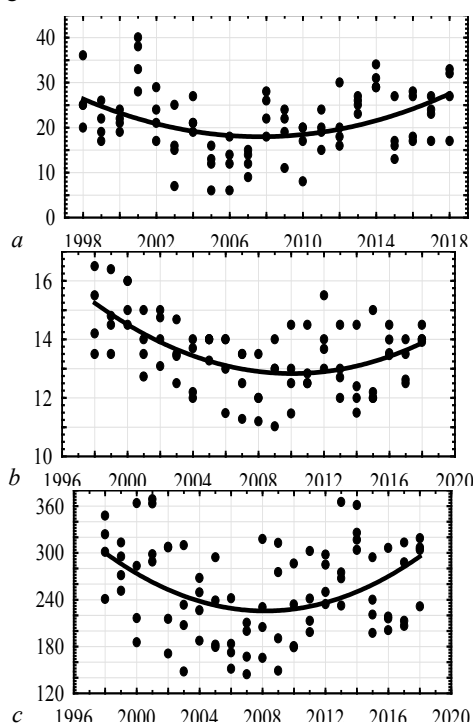


Fig. 9. Trends in the variability of the *Carassius gibelio* spawning characteristics in time: the horizontal axis – the sequence of years; ordinate axis: *a* – spawning duration (days), *b* – water temperature at the start of spawning (°C), *c* – cumulative temperature during the spawning period

The biotopic specificity of the spawning sites has a statistically reliable effect on the start time of spawning. Most early *C. gibelio* spawning was observed in ponds of the River Protoch system and Obukhov floodplain and Taromske ledge (Fig. 11). After all spawning takes place in the mainstream of the River Dnipro. The climate principal components and types of the lake systems can explain the 70% of the variation in the timing of the end of spawning. The temperature principal components 3 and 6 have a positive and statistically significant effect on ending of the spawning period. These principal components reflect the variability of temperature ranges, which mostly occur in winter, i.e. significantly earlier than the spawning period. During spawning the principal components 3 and 6 are almost not distinguishable from zero. This suggests that the duration of spawning is determined by the conditions and regimes of overwintering of this fish, which affects their reproductive and biological status. The principal component 2 indicates that if a relative decrease in precipitation pushes the start of spawning, this same factor promotes more rapid completion of the spawning period. The spawning period is the longest in the

wake of the Dnipro River. The quickest spawn period takes place in the River Protoch system and the Obukhov floodplain.

The climatic principal components and type of water body determine 56% of variation in the duration of spawning. The temperature principal components 1, 2, 4 and 5 and the principal component of variation in precipitation 2 have a statistically significant effect on the duration of spawning.

Table 4

Regression dependence of time of start, end, duration of spawning, water temperature at the start of spawning, cumulative temperature of *Carassius gibelio* spawning from the biotope type and principal components of variation in temperature and precipitation (standardized regression coefficients \pm SE, statistically significant with $P < 0.05$)

Predictors	Start	Termination	Duration	Water temperature at the start of spawning	Cumulative temperature of spawning
	$R^2_a = 0.79$	$R^2_a = 0.70$	$R^2_a = 0.56$	$R^2_a = 0.69$	$R^2_a = 0.60$
Temperature principal components					
Term1	-0.14 ± 0.07	–	0.28 ± 0.10	–	0.30 ± 0.10
Term2	0.18 ± 0.08	–	-0.28 ± 0.11	–	-0.26 ± 0.11
Term3	–	0.52 ± 0.16	–	-0.44 ± 0.16	–
Term4	–	–	0.28 ± 0.14	–	–
Term5	0.28 ± 0.06	–	-0.30 ± 0.09	–	–
Term6	0.23 ± 0.11	0.27 ± 0.13	–	0.64 ± 0.13	–
Term7	–	–	–	–	–
Term8	–	–	–	–	–
Precipitation principal components					
Precip1	–	–	–	0.52 ± 0.16	–
Precip2	0.28 ± 0.07	-0.18 ± 0.08	-0.58 ± 0.10	–	-0.38 ± 0.09
Precip3	–	–	–	-0.19 ± 0.09	–
Precip4	–	–	–	-0.82 ± 0.16	–
Precip5	0.23 ± 0.11	–	–	0.46 ± 0.14	–
Biotopes					
Biotope 1	–	0.33 ± 0.12	–	0.84 ± 0.12	0.94 ± 0.14
Biotope 2	-0.72 ± 0.10	-0.89 ± 0.12	–	-0.36 ± 0.12	–
Biotope 3	1.19 ± 0.10	0.85 ± 0.12	-0.68 ± 0.14	-0.60 ± 0.12	-0.50 ± 0.14
Biotope 4	-0.59 ± 0.10	-0.30 ± 0.12	0.48 ± 0.14	–	-0.55 ± 0.14

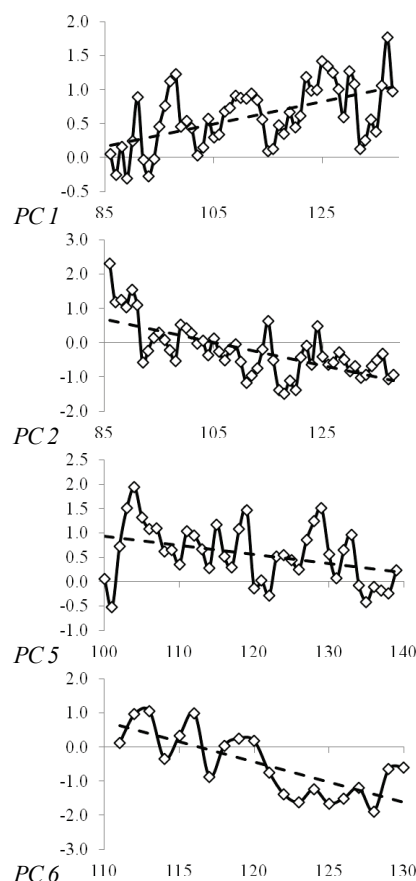


Fig. 10. The trajectory in time of the temperature principal components 1, 2, 5 and 6: the axis of abscissa – the number of days from the beginning of the year, the axis of ordinate – principal components scores

Between the timing of the onset of *C. gibelio* spawning and spawning duration there was a negative correlation ($r = -0.60$, $P < 0.001$), whereas the correlation with timing of the spawning termination is not statistically significant ($r = 0.16$, $P = 0.14$) (Fig. 12). Therefore, the duration of spawning is more dependent upon the spawning start time: the sooner the spawn begins, the longer it lasts. This explains the conflicting signs from the regression coefficients for the start time of spawning and for the duration of spawning. The greatest duration of spawning was found in the water bodies of the Taromske ledge and River Protoch system and the Obukhov floodplain.

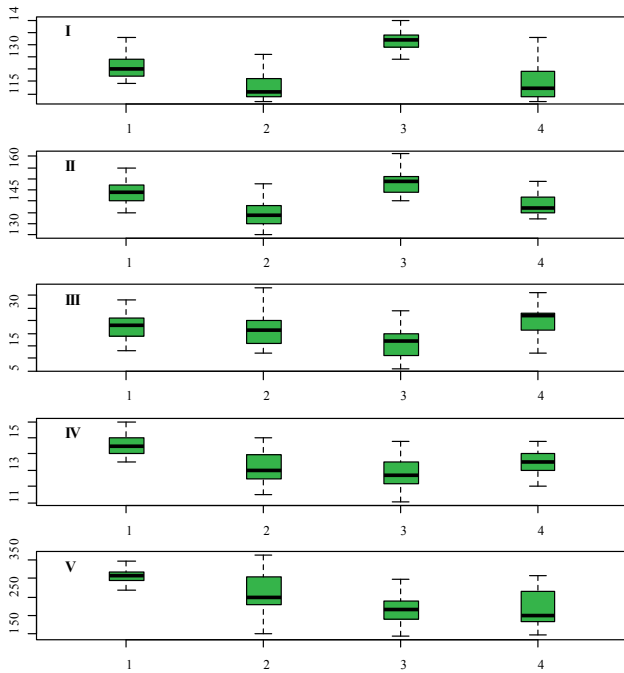


Fig. 11. The dependence of the timing of the onset of *Carassius gibelio* spawning (I, days of the year), the timing of the end of spawning (II, days of the year), spawning duration (III, the number of days), the water temperature at the start of spawning (IV, °C), cumulative temperature during spawning (V, °C) on the biotope type (whiskers – the minimum and maximum, box – the first and third quartiles, horizontal line – median): I – Nikolayev system of water bodies; II – River Protoch system and Obukhov floodplain; III – the channel of the River Dnipro; IV – Water bodies of the Taromske ledge

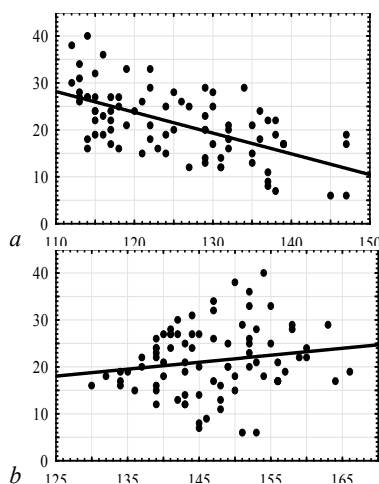


Fig. 12. Dependence of the *Carassius gibelio* spawning duration (y-axis, days) from the timing of the onset of spawning (a) and timing of the end of spawning (b) (days from the start of the each year)

There is no correlation between the time of spawning start and the water temperature at the start of spawning ($r = 0.09$, $P = 0.38$). Nevertheless, 69% of the water temperature variation at which spawning begins can be described by climatic predictors and water biotope types. Temperature principal components 3 and 6 are statistically significant predictors of the water temperature at the start of the *C. gibelio* spawning. The principal component 6 is a statistically significant predictor of both the start and duration of spawning, and the water temperature at the time of spawning. The water temperature at the start of spawning also depends on the precipitation regime, as evidenced by the statistically significant effect of the principal components of varying precipitation 1, 3, 4, and 5. The highest temperature of the water at the start of spawning was revealed for the Nikolayev system of water bodies, but the lowest temperature was in the channel of the River Dnipro.

The water temperature at the time of *C. gibelio* spawning was exposed to natural dynamics in year aspect. The local minimum of the start of spawning temperatures was revealed in the mid 2000s. The most constant *C. gibelio* spawning start temperature is especially the case for water bodies of the Nikolaev ledge. Very high variation of this indicator is found for water of the water bodies of the Taromske ledge and channel of the River Dnipro.

The duration of spawning and cumulative temperature during the spawning period are positively correlated ($r = 0.61$, $P < 0.01$), which explains the similar list of statistically significant predictors for these indicators of the *C. gibelio* spawning. Cumulative temperature is characterized by the biotopic specificity. This parameter is highest for the Nikolayev system of water bodies, and the lowest – for the Dnipro river bed.

The climatic factors and the type of habitat can explain 79.6% of variation of the *C. gibelio* spawning start time (Fig. 13).

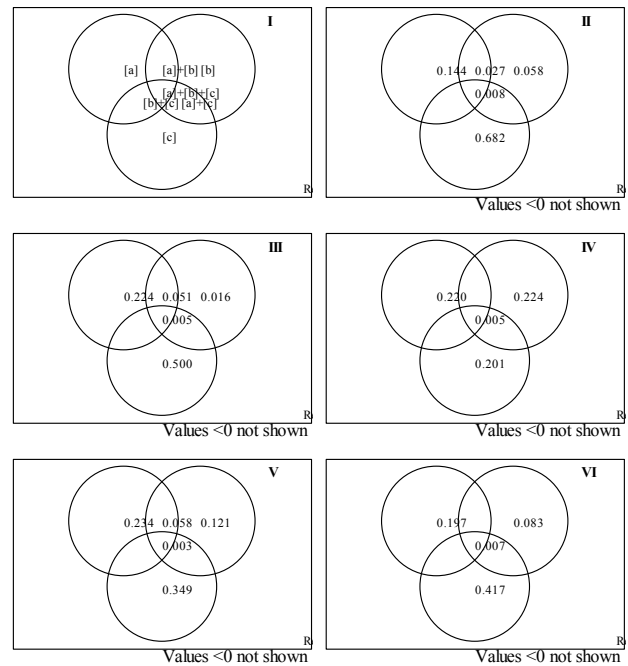


Fig. 13. The variation partitioning of the *Carassius gibelio* spawning parameters: I – variation components: [a] – temperature principal components, [b] – precipitation principal components, [c] – biotope type, [a] + [b] – mutual influence of the temperature and precipitation, [a] + [c] – mutual influence of temperature and biotope type; [b] + [c] – the mutual influence of the biotope type and precipitation, [a] + [b] + [c] – mutual influence of all factors; II – variation partitioning of the start time of spawning; III – variation partitioning of the termination time of spawning; IV – variation partitioning of the spawning duration; V – variation partitioning of the water temperature at the start of spawning; VI – variation partitioning of the cumulative temperature during the spawning

The spawning start time variation is mainly caused by the biotope type (68.2%). The air temperature regime plays an important role (14.4%). The precipitation regime plays a somewhat smaller role

(5.8%). The temperature and precipitation patterns interact, which determines 2.7% of the starting time variation. The interaction of climatic factors, which has biotopic specificity, determines 0.8% of the variation of this spawning index. The variation structure of the spawning termination time is determined at 70.3% by the biotope type and climatic factors. The temperature control is more important for this spawning indicator (22.4%) in comparison with the start time, while the role of the precipitation regime is reduced (1.6%). Also the role of the interaction of thermal and precipitation regimes was revealed as increasing. The spawning duration is in a lesser degree dependent on the considered factors than the start or termination time of the spawning (56.6%). This decrease was due to the reduction of the role of the habitat type (20.1%). It should be noted that the precipitation regime plays an important role in variation of the spawning duration (22.4%).

The environmental factors explain 69.3% of the water temperature variation at the start of spawning. The type of habitat plays a greatest role in the variation partitioning of this indicator (34.9%). Obviously, the dynamic of the atmospheric temperature is superimposed by the hydrological regime of reservoir, which creates both the temperature and the water level regime specific for each water body. The latter circumstance acts as a stimulus for spawning, thereby spawning can occur in different water bodies at different water temperatures. The cumulative temperature during spawning is to an even greater extent determined by the biotope type (41.7%). The role of the temperature regime for this measure is much more significant than precipitation patterns.

The temperature principal components 5, 6 and 8 with the precipitation principal components and the biotope type as covariates play the greatest role in variation of the start time of spawning. This result once again underlines the important role of the temperature factor in the regulation of the dynamics of *C. gibelio* spawning. Account of precipitation and biotope type as covariates significantly increases the variation of the time of spawning termination explained by the temperature principal components. The principal component 6 plays the most important role. The duration of spawning is an indicator of a complex nature, as evidenced by the large number of statistically significant predictors from the temperature principal components – 2–7. Accounting covariates significantly increases the variance explained by principal components 2–6. The water temperature at the start of spawning is best explained by temperature component 6.

Thus, the variation explained by some temperature principal components may be increased considerably after including as covariates such variables as the precipitation principal component and the biotope type. The principal component 6 has the highest explanation ability of all the components and is a constant explanatory predictor for all considered spawning characteristics. This principal component represents the high frequency variation of the air temperature regime with the characteristic period of 20 and 45 days. Among the precipitation principal components the principal component 2 has the greatest importance in explaining the variation of spawning (Fig. 15). The descriptive ability of precipitation principal component 2 may be increased significantly after including temperature principal component and the biotope type as covariates. The principal component 4 has an important role in describing the variations of the water temperature at the start of spawning. The explanatory ability of principal component 4 is the greatest without covariates, so it can be assumed that the interaction of temperature and precipitation regime considerably affects the variation in temperature of the water at the start of spawning.

Discussion

To explain the phenology of *C. gibelio* spawning, we proceed from the assumption that spawning occurs after exposure to a stimulus, but the readiness of fish to spawn is determined by the features of life in a significant period of time that precedes spawning. Temperature is a fundamental physical regulatory factor in the lives of fishes (Pankhurst & Munday, 2011). After spawning in the previous year, the silver Prussian carp was observed to have a quiescent period and then a rapid growth phase of the gonads took place (Emiroğlu et al., 2012). Food supply and climatic conditions during this period affect the dynamics of the process. The photoperiod and temperature are generally regarded as the most significant

cues in the timing of gametogenesis and spawning in temperate zone fish (Migaud et al., 2002). Our hypothesis is that regular patterns of temperature and precipitation are the controlling factors that determine the characteristics of spawning. In reproductively mature adults, temperature is generally seen to be a secondary cue to photoperiod in phasing reproductive seasonality but it has an important role in synchronising the final phases of reproductive maturity (Pankhurst & Porter, 2003). Certain climatic fluctuation modes can be a source of misinformation as incentives for spawning. For example, the abnormal warming in the late winter can be a stimulus for spawning, as after that the inevitable death of offspring will follow. Thus, only the regular sequence of climatic conditions can act as a control factor.

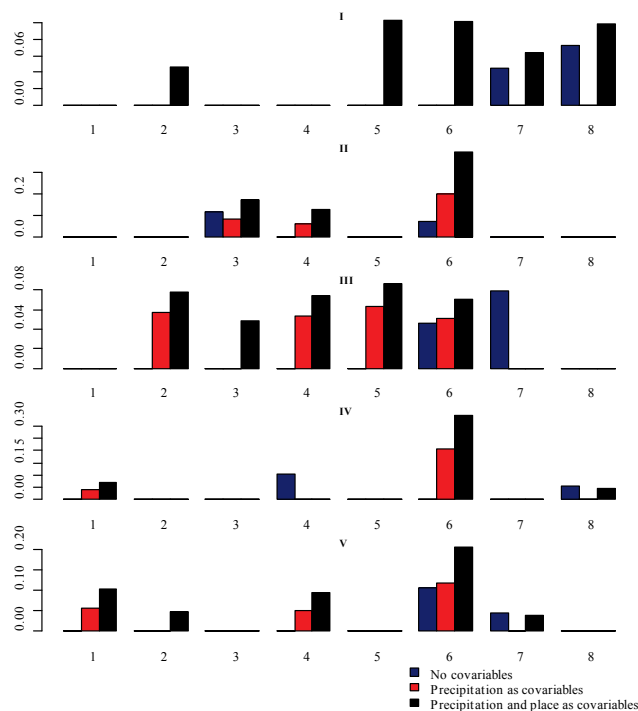


Fig. 14. Scalograms illustrating the scaling of the influence of temperature principal components on the parameters of the *Carassius gibelio* spawning: x-axis – numbers of the temperature principal component; y-axis – R2adj, I – the start of the spawning, II – end of the spawning; III – duration of spawning; IV – the water temperature at the beginning of the spawning period; V – cumulative temperature for spawning period

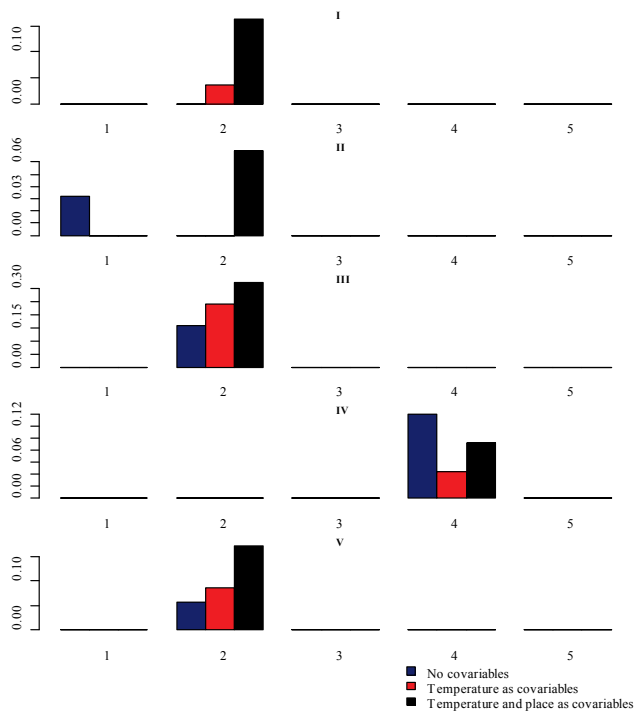


Fig. 15. Scalograms illustrating the scaling of the influence of precipitation principal components on the parameters of the *Carassius gibelio* spawning: x-axis – numbers of the precipitation principal component; y-axis – R^2_{adj} , I – the start of the spawning, II – end of the spawning; III – duration of spawning; IV – the water temperature at the beginning of the spawning period; V – cumulative temperature for spawning period

The air temperature at the surface of the Earth is one of the most important ecological factors (Ye et al., 2013). The deviations from the seasonally integrated course of the temperatures and precipitation may be represented as a recurring oscillatory process. The effects of temperature can be differentially expressed depending on when in the annual thermal cycle spawning normally occurs, with increasing spring temperatures being required to cue maturation in spring and early summer spawners (Scott & Pankhurst 1992; Shimizu, 2003). Deterministic processes may be used to characterize the variation patterns of the seasonal trend of the temperature signal involving polynomial functions (Ye et al., 2013). Coherent rhythms are presented as the principal components. Temperature has a similarly important role in the modulation of post-fertilisation processes both through its rate-determining effects on embryogenesis and hatching (Pauly & Pullin, 1988) and subsequent larval development, growth and survival (Sponaugle & Cowen 1996; Pankhurst & Munday, 2011). Temperature and precipitation principal components have a significant predictive capability for explaining the timing of the beginning, end and duration of spawning.

An important feature is that the water temperature at the start of spawning can also be explained by climatic principal components. The critical temperature is regarded as a trigger that starts the process of spawning. Our research shows that this index is a function of climatic conditions. Obviously, the sensitivity to thermal stimulus depends on the organism condition of the fish, which is determined by the peculiarities of life conditions for the long previous period.

The principal components of climatic regimes vary over a long period of time. The events that immediately precede spawning are most likely to be the greatest influence for adjusting the timing of spawning. The early springtime rapid warming in combination with a higher rate of precipitation stimulates an earlier date of the onset of spawning. However, such events are coordinated with the dynamics of climatic processes at an earlier stage – in autumn or early winter. And there is no statistical reason to reject the hypothesis that the particular environmental conditions do not affect or do not significantly affect the phenology of spawning fish. Statistically and biologically the hypothesis that the environmental conditions during the life of the fish after the previous

spawning determine the spawning phenology of the current year is quite realistic.

Conclusion

The temperature and precipitation patterns are characterized by regularities of seasonal rhythms. Deviations from the long-term trend are the specifics of the course of temperatures and precipitations of a current year. The principal component analysis showed that 59.2% of the temperature variation trend residues may be represented as 8 principal components and 82.6% of the residual variation from trend of precipitation can be represented as 5 principal components. Climatic principal components have significant explanatory power to describe the events of spawning of Prussian carp (start, end and duration of spawning). Rapid warming in spring in combination with higher precipitation than normal can stimulate earlier spawning. The duration of spawning is largely dependent on the time of its inception: the earlier is the start of spawning, the longer is the period of spawning. Climatic features in the spawning period are adjusted to the greatest extent during its closure. Water temperature at the start of spawning is dependent on the climatic conditions.

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