SPRING ECOLOGICAL REGULATION OF THE TRANSBOUNDARY DNIESTER RIVER FLOW – A WAY TO PRESERVE BIOLOGICAL RESOURCES

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Abstract. The article presents the results of the international team (Republic of Moldova and Ukraine) three-year research dedicated to assessment of the spring ecological flow parameters, organized on the transboundary regulated Dniester River, with a scope to imitate the natural river spring flood. The flood is organized in order to create the close to natural conditions for spawning of phytophilic fish species (*Cyprinus carpio, Carassius auratus gibelio, Rutilus rutilus, R. heckelii, Abramis brama, Blicca bjoerkna*, etc.) in the Lower Dniester – the most valuable basin area from the viewpoint to preserve the fish resources and aquatic biodiversity richness. There were analyzed in detail the hydrological and temperature regimes before and during spring ecological flows in 2022-2024, the coverage of spawning grounds as well as the process of fish gonads maturation. As a result, the most efficient regimes of the ecological flow were determined. It was stated the water temperature is the main factor, which determines the spawning time, while the flow volume and its regime determine the spawning grounds availability for phytophilic fishes. The amount of water available for ecological flow formation has to be higher than 1 km^3, the period of flooding 25-30 days, with maximum flow at least 700-800 m^3/s. From three years of the research only 2023 could be considered as optimal for ecological flood organization, while in spring 2022 there was a strong water deficit, also repeated in 2025. Because the main hydropower facilities are situated in Ukraine, the close cooperation of both countries is necessary to coordinate the spring ecological flow management. To solve this and other issues dealing with the river basin management the Dniester River basin commission was established in the frames of the bilateral intergovernmental Dniester treaty (2012).

Keywords: the Dniester River, spring ecological flow, fish reproduction.

Rezumat. Viitura ecologică de primăvară pe fluviul Nistru transfrontalier reglat de baraje – o cale spre conservarea resurselor biologice. Sunt prezentate rezultatele cercetărilor pe o durată de trei ani (2022-2024) ale echipei internaționale (Republica Moldova și Ucraina) privind evaluarea parametrilor debitului ecologic de primăvară organizat pe fluviul Nistru cu scopul de a imita viitura naturală de primăvară în vederea creării condițiilor apropiate de cele naturale pentru reproducerea speciilor de pești fitofili (*Cyprinus carpio, Carassius auratus gibelio, Rutilus rutilus, R. heckelii, Abramis brama, Blicca bjoerkna,* etc.) în Nistrul de Jos – zona cea mai importantă din punctul de vedere al biodiversității acvatice. S-au monitorizat regimurile hidrologic și termal în ajunul și în timpul primăverilor acestor ani, inundarea spațiilor de boiști, precum și procesul de maturare a gonadelor la pești. Ca rezultat au fost identificate cele mai eficiente regimuri ale debitului ecologic. S-a demonstrat că temperatura apei constituie factorul principal ce determină perioada de reproducere, iar volumul și regimul debitului determină disponibilitatea spațiilor de boiști. Cantitatea de apă în lacul de baraj Dnistrovsk necesară pentru organizarea deversării ecologice nu trebuie să fie mai mică de 1 km^3, perioada de inundație trebuie să dureze 25-30 de zile cu debitul maxim de cel puțin 700-800 m^3/s. Dintre cei trei ani doar în anul 2023 deversarea ecologică poate fi considerată optimă, pe când primăvara anului 2022 a fost cu un deficit mare de apă, această situaţie repetându-se şi în anul 2025. Deoarece principalele construcţii hidroenergetice pe fluviu sunt situate în sectorul din amonte din Ucraina, este necesară o cooperare mai strânsă dintre ambele state pentru a coordona eficient managementul debitului ecologic de primăvară. Comisia pentru bazinul fluviului Nistru este înființată în cadrul Tratatului interguvernamental bilateral privind Nistru (a. 2012) pentru a soluţiona această și alte probleme legate de managementul acestui important bazin hidrografic.

Cuvinte cheie: fluviul Nistru, debitul ecologic de primăvară, pește, reproducere.

INTRODUCTION

Spring river floods are a well-known phenomenon to which aquatic biota, in particular fish, are adapted. The meadows, flooded by rising water, act as spawning grounds where phytophilic fish lay eggs. Ideally, the period of flooding should correspond to suitable temperatures at which the development of embryos in eggs occurs. Premature decrease in water level, as well as a sharp decrease in temperature, lead to eggs death. At the same time, in regulated rivers, on which the hydroelectric power plants (HPP) are built, the spring flooding depends on their operating mode. Therefore, to ensure successful fish spawning, it is necessary to create the conditions of a natural spring flood. In this case, many factors should be taken into account: the sufficiency of water reserves and possibility of additional runoff from the basin's upper part, the forecast of water and temperature conditions, the conditions of fish reproductive products and degree of their readiness for spawning, the conditions of spawning grounds, etc.

As noted in previous works, which were summarized by GULYAEVA & DENISOV (2020), the efficiency of the Dniester's *spring ecological flood* (*SEF*) depends on the volume of water accumulated in its reservoirs and the amount of runoff from the Upper Dniester during floods and their duration, the planned and actual hydrological regime, the fluctuations in air and water temperatures during the water release period. At the same time, these authors note that in order to increase the ecological floods efficiency, the additional studies are required aimed at determining the optimal water temperature for the start of an ecological water flood, the quantitative assessment of relationships between ecological needs of spawning grounds conditions of the Dniester lower ecosystems reaches and the hydrological parameters of the flood with the justification of the requirements in terms of flooding of the floodplains.

The present study, based on the regulated Dniester River in 2022-2024, aimed to determine the optimal parameters of its spring ecological flows, taking into account water availability, temperature and hydrological regimes in each studied year, and access to spawning grounds of phytophilic fish species. It was done in order to improve the operating mode to optimize the operation of the hydroelectric power plants (HPP) of the Dniester Hydropower Complex (DHC) and the Dubăsari HPP to create the most optimal fish spawning conditions. The work was carried out by the team of hydrologists and ichthyologists from Chișinău, Tiraspol and Odessa.

MATERIAL AND METHODS

Hydrological data were provided by the State Hydrometeorological Services (SHS) of Moldova, the Agency "Apele Moldovei" and authorities from Ukraine (especially data on Dnistrovsk reservoir and Mayaki hydrological station), as well from the site http://dnister.meteo.gov.ua. The main indictor allowing the assessment of water resources is the streamflow, evaluated at the hydrological stations: representing the water inflow into the Dnistrovsk resservoir, from its outflow (considered as one from the DHC, the inflow and outflow from the Dubăsari reservoir and at the Bender and Talmaza hydrological stations. The water temperature was analyzed for Dnistrovsk and Dubăsari reservoirs (res.) and at hydrological posts Soroca, Criuleni, Bender, Talmaza, Răscăieţi, Tudora and Mayaki.

The relationships between flooded areas and water flow in the Lower Dniester region were assessed through their correlation based on the Landsat satellite images extracted from https://earthexplorer.usgs.gov/.

Ichthyological field investigations covered mainly the periods March-June of 2022-2024. During the reproductive migration and ~~the~~ development of phytophilic fish reproduction, the observations were carried out as frequently as possible in each trimester. In order to assess the efficiency of phytophilic fish reproduction (post-reproductive state of gonads, numerical abundance, spread of larvae and fry), research was also carried out during the rest of the vegetative period (July - October).

Within the studied perimeter (Fig. 1) the stations for collecting ichthyological material were selected in accordance with the principles coordinated by the project working groups, namely: hydrobiotopes with heterogeneous characteristics and wide variations in abiotic and biotic parameters (according to the longitudinal distance between the spawning grounds, the nature of the flood, bottom sediments and substrates for spawning, the degree of overgrowth with hydrophytes, hydroecological differences, the structure of the ichthyocenosis, the accessibility of the spawning grounds in different weather conditions and the possibility of using various fishing tools in them in a specific period and situation, etc.).

Monitoring of the phytophilic fish species reproduction of the Lower Dniester area was carried out annually in the spawning grounds located on the river both banks, including its Turunchiuk branch.

The fish (adult fish, fry, larvae and eggs) were captured using various tools: seine net (Ø 6.0 mm, *l* 6.0 m and *h* 2.0 m); drag net (Ø 20 mm, *l* 15 m and *h* 2.5 m); stationary gill-nets (Ø 12-100 mm); floating gill-nets (Ø 14-90 mm); fyke net (Ø 6-50 mm); shrimp net (Ø 4-16 mm); cast net (Ø 4-20 mm); landing net; Corey net; rods and fishing lines with different rigs. We also conducted a survey of amateur fishermen and analyzed the fish from their catches. Useful information on the locations and terms of reproduction of phytophilic fish in Lower Dniester were also kindly provided by the ecological inspectors (Table 1).

For the convenience of analyzing the maturation rate of germinal products and delimiting certain stages of their sexual cycle, a number of scales have been developed, applicable to different species and ecological groups of fish (CEPURNOVA, 1991). Based on macro- and microscopic characteristics, a simple and universal scale has been developed, consisting of six main stages of gonadal development and maturation of germ cells:

Stage I – Juvenility. Ovaries and testes very small, in the form of long ribbons, located close to the spine, ovaries light pink to white, sex cells are not distinguishable. With the naked eye, sex often cannot be determined by the external appearance of gonads.

Stage II – Rest. Gonads are very small, thin, grayish-pink, more and less symmetrical. Testicles are transparent. Germ cells either have not yet begun to develop or have already been swept away. Eggs are so small that they are not distinguishable with the naked eye. In adults, this is the resting stage that sets in after spawning. At further maturation, gonadal development begins from stage II. Sex is usually determined by the blood vessel: on the ovaries there is a large one, on the testicles it is absent.

Stage III – Maturation. Gonads occupy almost two-thirds of the abdominal cavity, ovaries are red-orange and testicles become pale pink. Oocytes are visible to the naked eye, testicles are creamy white, when pressed they do not release sperm.

Stage IV – Maturity. Gonads have reached maximum volume and weight, occupy the entire abdominal cavity, when lightly pressed on the abdomen they emit eggs and sperm. Testicles are milky white, ovaries - orange-reddish; eggs are spherical in shape and are visible to the naked eye (Figs. 2 and 3).

Stage V – Reproduction. Sexual products are eliminated when lightly pressed on the abdomen. Eggs are transparent and large, opaque and immature eggs are also visible in the ovaries.

Stage VI – Post-reproduction. The genital opening is inflamed. The emptied gonads, soft and wrinkled, occupy about half of the abdominal cavity; the ovaries are strongly vascularized, may still contain degenerated eggs; the testicles with undeleted sperm remains.

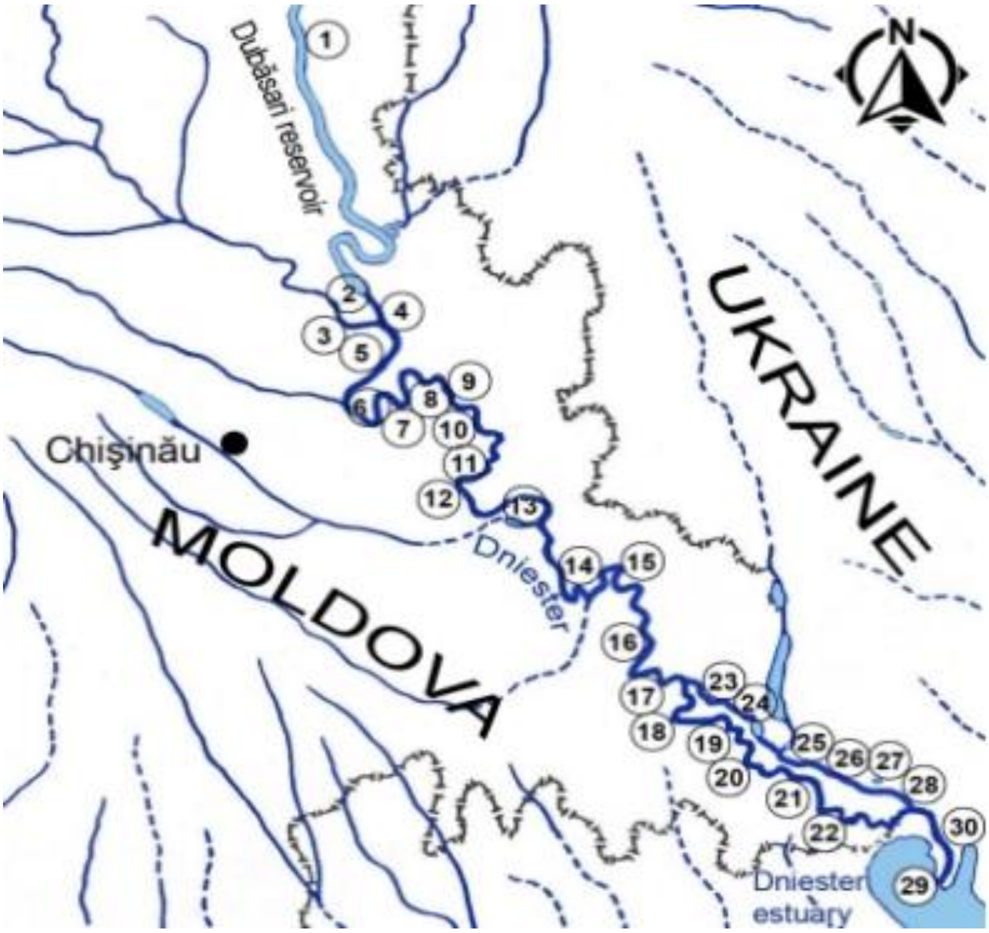

Figure 1. Locations of points for ichthyological research on the assessment of the phytophilic fish reproduction course in the Lower Dniester River basin in 2022-2024.
1. Ofatinţi village; 2. Dubăsari HPP – Ustia village; 3. Ustia village; 4. Confluence Răut River – Dniester River; 5. Criuleni town; 6. Mălăieşti village; 7. Corjova village; 8. Dubăsarii Vechi village; 9. Grigoriopol town; 10. Delacău village; 11. Şerpeni village; 12. Teliţa village; 13. Gura-Bâcului village; 14. Parcani village; 15. Sucleia village; 16. Cremenciug village; 17. Talmaza village; 18. Ciobruciu village; 19. Răscăieţi village; 20. Purcari village; 21. Olăneşti village; 22. Tudora village; 23. Corotna village; 24. Kuchurhan Reservoir; 25. Putryne Lake; 26. Iaske village; 27. Bilyayivka town – Popove Lake; 28. Bilyayivka town; 29. Dniester Estuary; 30. Karagol Bay (original).

Table 1. Samples of phytophilic fish from the Lower Dniester River subjected to ichthyological examination, 2022-2024 (right bank MD / left bank MD / UA / total for fish species).

Fish species	**2022**	**2023**	**2024**
Common carp *Cyprinus carpio* Linnaeus, 1758	15/7/14/36	11/5/12/28	9/3/14/26
Crucian carp *Carassius auratus* (L., 1758) */ C.auratus gibelio* (Bloch, 1782)	30/92/51/173	32/116/31/179	36/64/44/144
Common bream *Abramis brama* (L., 1758)	20/3/12/35	31/5/11/47	28/8/18/54
Rudd *Scardinius erythrophthalmus* (L., 1758)	0/0/41/41	0/0/11/11	0/0/18/18
Tench *Tinca tinca* (L., 1758)	0/0/0/0	0/0/0/0	0/0/7/7
White-eye bream *Ballerus sapa* (Pallas, 1814)	10/0/0/10	38/0/0/38	1/5/0/6
Silver bream *Blicca bjoerkna* (L., 1758)	35/1/35/71	28/11/21/60	31/9/39/79
Bleak *Alburnus alburnus* (L., 1758)	7/0/22/29	46/0/9/55	65/0/17/82
Roach / Taran *Rutilus rutilus* (L., 1758) */ R.heckelii* (Nordmann, 1840)	30/21/66/117	31/108/27/166	30/215/51/296
Pike *Esox lucius* L., 1758	6/0/11/17	5/2/11/18	6/6/12/24
Perch *Perca fluviatilis* L., 1758	19/6/31/56	17/11/15/43	27/43/36/106
Pike-perch *Sander lucioperca* (L., 1758)	70/0/6/76	13/0/7/20	14/2/11/27
Total:	**661 ex.**	**665 ex.**	**869 ex.**

The moment of simultaneous presence of females and males in the spawning grounds, detection of flowing eggs in some females, the appearance of females that have already reproduced - with signs of laid eggs, stage VI of egg maturation, as well as eggs stuck to hydrophytes and fishing gear is considered evidence of the beginning of reproduction. In the case of mass reproduction, females with flowing eggs are found in large numbers in catches from the bog areas. At the end of reproduction, only single specimens of females with flowing eggs and numerous females at stages V-VI of maturation are caught, the eggs of many fish species adhere to last year's vegetation or that in the current vegetation (rhizomes of reeds or sedge, tree roots and stands, etc.).

As a rule, the assessment of the period of ecological flow, as favorable/unfavorable for fish reproduction, can be made only on the basis of the results of ichthyological research on the maturation of seminal products and on the course of the fish reproduction process itself - the chronological coincidence of the flooding of the spawning grounds and the spawning of the main phytophilic fish species indicates the efficiency of reproduction.

Figure 2. Common carp female, stage of gonads maturity IV. Lower Dniester, Ukraine, April 10, 2024 (original).

Figure 3. Bream female, stage of gonads maturity IV. Lower Dniester, Ukraine, April 14, 2022 (original).

The optimal regime of water flow, excluding the thermal one, has a small effect on fish reproduction. Therefore, monitoring the state of the gonads in relation to water temperature is the most suitable method for determining the beginning of the favorable period of maximum water discharge from the DHC reservoirs, when the largest areas of the spawning grounds can be flooded. Data on the dynamics of maturation of fish seminal products and survival of offspring are mandatory in monitoring and assessing the efficiency of ecological flood.

The relevance of ichthyological information on fish reproduction for making decisions to optimize ecological discharges is that period (beginning, end and repetition) of these floods should coincide both with the moment of migration and reproductive concentration of fish, reproduction and spawning (ensuring the necessary water level for flooding the ponds and their entry into them), as well as with the moment of exit of the larvae and fry from the shallow waters into the main riverbed (in the case when the breeding sites are not located in the riverbed).

RESULTS

The cascade of reservoirs built on the Dniester River bed has led to changes in hydrological regime of the Dniester River, including the spring floods phase. As a result, a new subphase of spring floods, conventionally called *a spring ecological flood (SEF)*, has formed. It is planned annually by Moldovan and Ukrainian experts and discharged from the DHC, in particular, during the fishing prohibition. The purpose of SEF is to provide sufficient water volumes in the Dniester riverbed to ensure reproduction of fish and stability of the river ecosystems.

According to analyzed information, four situations were identified for the planning process of SEF releases in the last three decades (JELEAPOV, 2022):

- SEF coincides with natural spring flood;
- SEF takes place after generation of spring flood;
- SEF coincides with the beginning or end of spring flood, being its component;
- SEF is released in the absence of spring flood.

The results of the present study's in-depth analysis of 2022-2024 conditions and detailed hydrological and thermal regime evaluation, recommendations for SEF development are described below.

Winter and spring flows. The average winter flows for 2022 and 2023 are characterized by values slightly above the norm upstream of the DHC (110-120% or 220-245 m^3/s) and below the norm downstream of the DHC, including in the lower course of the Dniester (about 80%, or 160-180 m^3/s). In 2024, the average winter flows were about 320-350 m^3/s, being higher than the norm by about 55-70%, without major spatial changes.

The average spring flows varied from year to year. In 2022, the flows were only 65% of the norm or about 220-240 m^3/s, without major spatial changes. In 2023, the average spring flows at the entrance to the DHC were slightly lower the norm, (by 12%); downstream of the DHC they were equal to the norm.

The spring of 2024 distinguished from other years by quite large spatial increases. The average spring flows in the DHC upstream part were about 58% of the norm (233 m^3/s); downstream they increased to 88-92% of the norm (300-360 m^3/s) (Figs. 4 - 6).

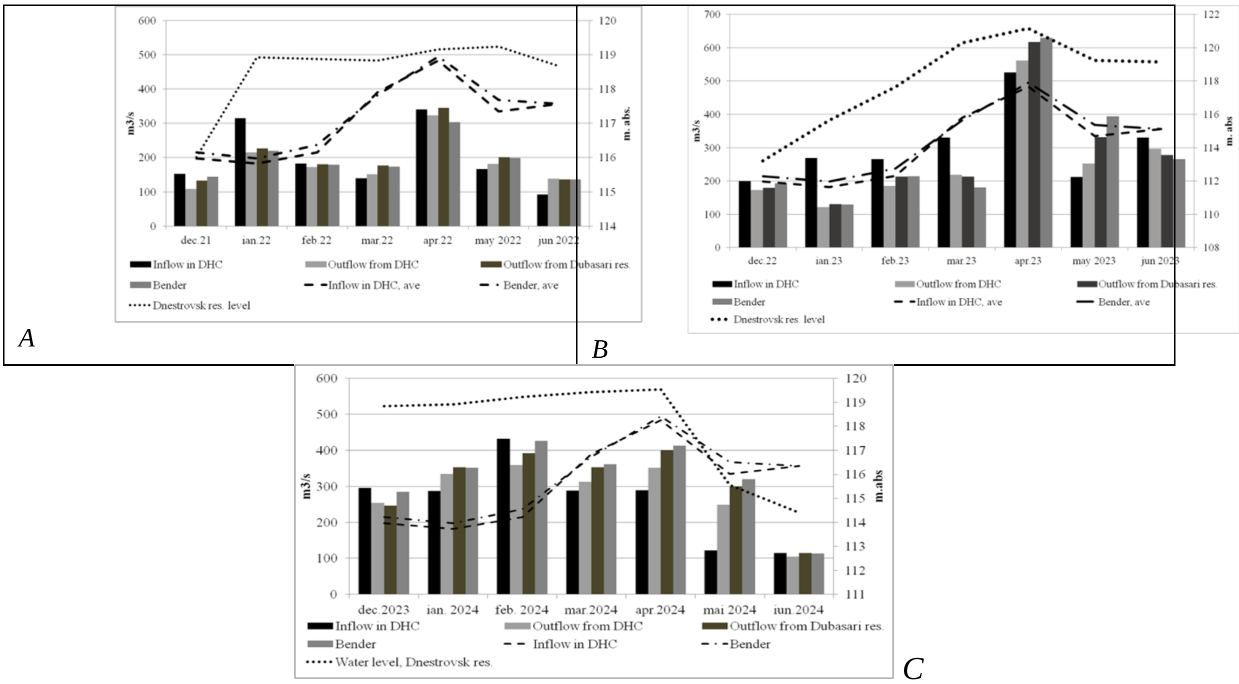

Figure 4. Variation in monthly flows.

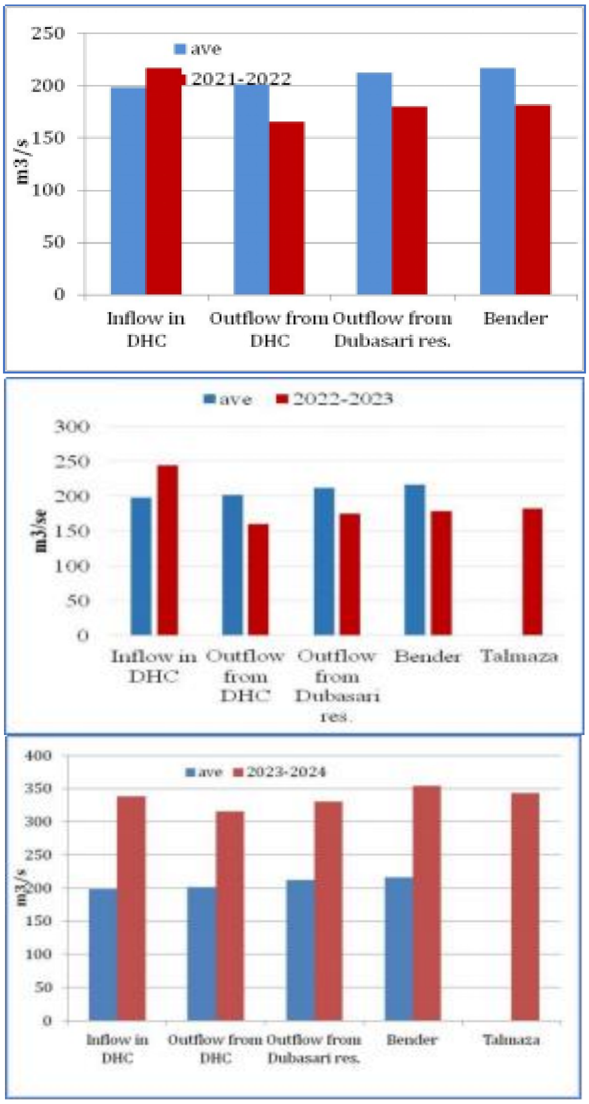

Figure 5. Variation of flows during the winter period.

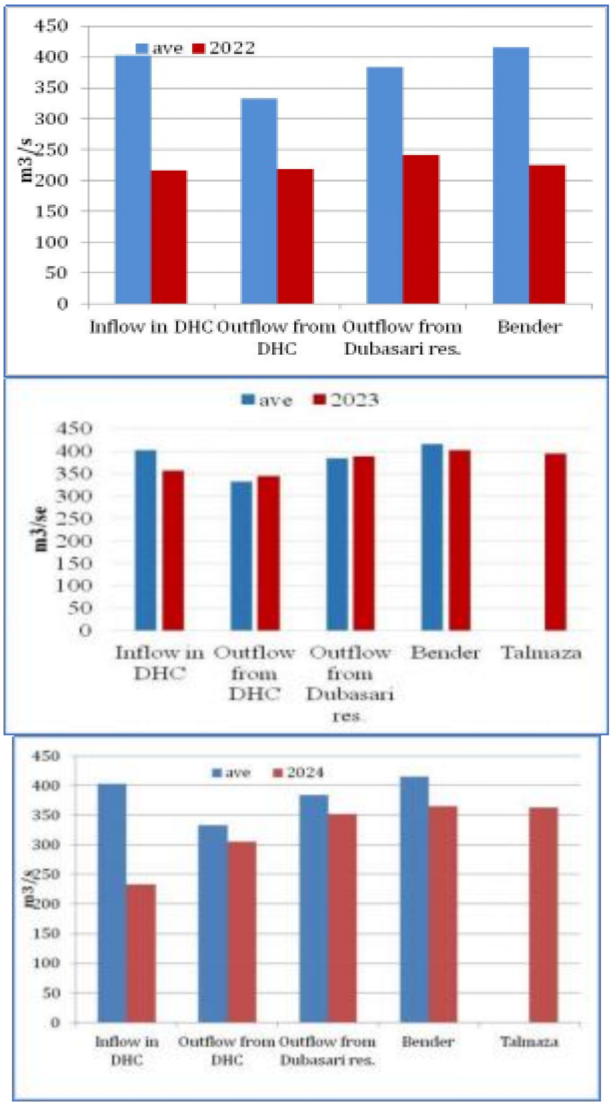

Figure 6. Variation of flows during the spring period.

Spring floods

2022. The meteorological conditions at the end of March - beginning of April and also those that occurred during April determined the formation of spring flood processes. The hydrograph of spring flood in natural regime was characterized by three waves with three characteristic peaks, the first being the largest and most important (the peak flow 868 m^3/s). DHC contributed to the natural flow modification to a certain extent, and under the DHC influence a new wave with a peak flow of 538 m^3/s appeared between the second and third natural waves. The outflow from the Dubăsari res. repeats that one from the Dnistrovsk res. without any essential changes. The time delay of the peak flows of four waves was 3-4 days, while the difference between their values was small. At Bender, the spring flood wave becomes uniform with the shape of the hydrograph similar to a triangle with a single peak flow of 554 m^3/s, or 314 m^3/s less than the natural one, 231 m^3/s less than the one discharged from the Dnistrovsk res. and 169 m3/s less than the one discharged from the Dubăsari res. Thus, in the three waves of spring flood formed in the natural regime (with peak flows of 868 m^3/s, 648 m^3/s, 439 m^3/s) in the regulated regime in the downstream course a single wave with a single peak of 554 m^3/s was highlighted, being 36% lower than the natural peak flow. The duration of the natural spring flood was about 17 days in total, and the flood wave from Bender about 8 days. The total volume of waves formed during the spring flood passage was over 500 mln. m^3, quite small for such hydrological event; the volume of the wave in the lower course amounted to approx. 280 mln. m^3.

2023. In 2023 the spring flood phase took place. In the natural regime, its period was quite long, starting on March 24 with flows of 258 m^3/s and ending on May 13 with flows of 235 m^3/s. The total duration of the flood was 51 day, the total water volume was 1910 mln. m^3, the average flow 439 m^3/s, the peak flow 1101 m^3/s that occurred on the 21st day from the beginning of the phase. The spring flood phase downstream of the DHC can be divided into two subphases. The first part corresponds to this phase beginning the in natural regime, and the second – to its end, also considered as an ecological flood. The shape of the subphases' hydrograph is trapezoidal; the part of peak flows being characterized by variations in flows. The first subphase begins with the spring flood phase and conventionally lasts until April 10 downstream of the DHC and until April 15 in the lower part of the river. The water volume downstream of DHC was 652 mln. m^3, downstream of the Dubăsari res. – 737 mln. m^3, at Bender and Talmaza – 810 mln. m^3. The peak flows downstream of DHC were 735 m^3/s, downstream of the Dubăsari res. – 920 m^3/s, at Bender – 737 m^3/s. The second subphase begins downstream of DHC on April 11 and ends on May 13, in the lower part it begins on April 17 and ends on May 20. The period between April 17 and May 12 is considered to be an organized ecological flood. The water volume downstream of DHC was 1570 mln. m^3, downstream of the Dubăsari res. –1622 mln. m^3, at Bender and Talmaza – 1750 mln. m^3. The peak flows downstream of DHC was 928 m^3/s, at Unguri – 1130 m^3/s, downstream of the Dubăsari res. – 877 m^3/s, at Bender –794 m^3/s (Fig. 7).

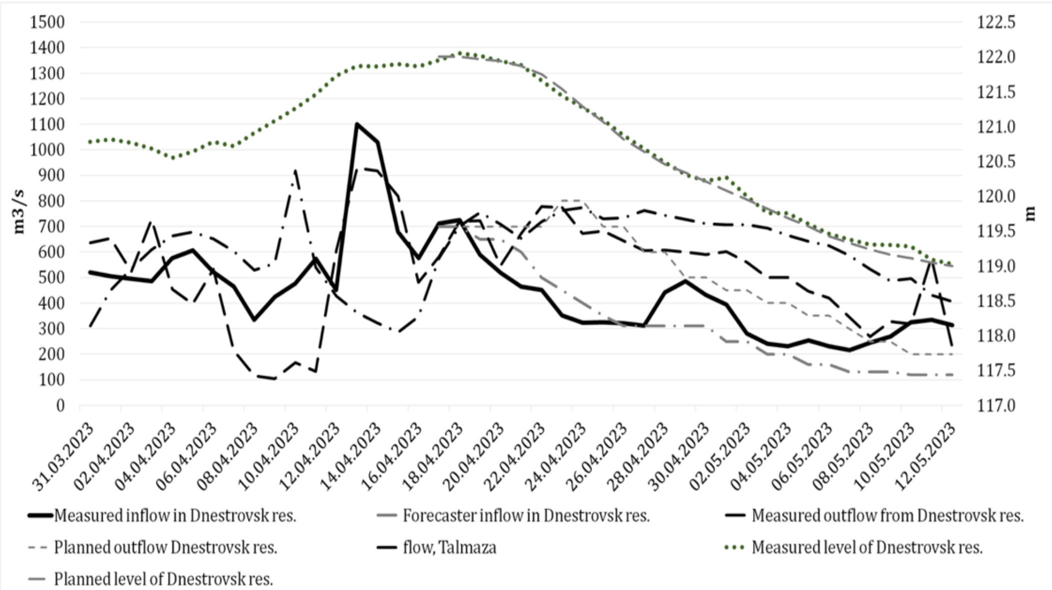

Figure 7. Spring ecological flood: the final scenario and the real situation (built based on Ukrainian and MD SHS data).

2024. In 2024, the spring flood was observed in February, being characterized by a peak flows of 700-900 m^3/s and a total volume of 760 mln. m^3 in the natural regime. In the regulated regime, downstream of DHC and Dubăsari res., the peak flows were reduced to 600 m^3/s, and the water volume to 660 mln. m^3. During the spring, in the natural regime between the second decade of March and the first decade of April a fluctuation was observed with a peak flow of 500-541 m^3/s, and a volume of about 750 mln. m^3. Subsequently, the water flows were decreasing to 80-200 m^3/s till the spring end.

Spring ecological flood

2022. Due to hydrological situation, characterized by flows much below the norm, as well as unfavorable weather forecasts for floods generation, the organization of SEF was not performed.

2023. The hydrological conditions in the period from the third decade of March to the first decade of May were characterized by the spring flood spread. The ecological flood was organized at the end of its phase, as a result of the water volumes formed in the upper part of the basin and of its significant volumes accumulation within the Dnistrovsk res. According to the final scenario approved by the representatives of both states, the optimal period chosen for the ecological flood implementation was April 17 - May 12, or 26 days. The proposed hydrograph was of a trapezoid shape, without an increasing limb. Peak flows were about 700-800 m^3/s with 10 days duration. The water level in the Dnistrovsk res. at the beginning of the flood was estimated to be 122 m, or 1 m above the normal retention level, with the volume being 2686 mln. m^3. Towards the flood end, the water level was estimated to decrease to 119 m, the water volume to 2282 mln. m^3, or by about 400 mln. m^3. The total planned volume of the flood was estimated to be 1123 mln. m^3, of which 725 mln. m^3 was the volume forecasted in natural regime and 400 mln. m^3 the compensation volume.

The real situation showed a picture relatively close to the planned one. The water level variation in the Dnistrovsk res. coincided with the planned one, diminishing from 121.95 m to 119.03 m or approx. by 3 m; the volume decreasing from 2675 mln. m^3 to 2289 mln. m^3; or by approx. 412 mln. m^3. During the planned period for the peak flow equal to 700 -800 m^3/s, the real outflows were 550-777 m^3/s. The planned flood volume was equal to 1123 mln. m^3, while the real discharged flood volume from Dnistrovsk res. was about 1215 mln. m^3. In this way, the real volume of the ecological flood exceeded the planned one by 91.8 mln. m^3.

In the Dniester lower part the flood wave has a longer duration and the peak water flows was higher and longer duration than they downstream of the DHC. The peak flows exceeded 700 m^3/s with duration of 16 days. The flood decreasing limb was quite long (about 17 days): the flows slowly decreased from 660 m^3/s to 160 m^3/s. The volume of the ecological flood in the lower part of the Dniester River, formed during April 17 - May 12, was 1.4 km^3. Respectively, in its lower part the hydrological conditions were much more favorable compared to the middle one for the development of ichthyofauna.

Finally, it should be emphasized that the hydrological situation in the spring of 2023 was favorable due to the water flows formed in the upper part of the river basin. The ecological flood was planned towards the end of the spring flood phase. In summary, the volume of the spring flood phase in the natural regime was 1.9 km^3 and the discharged one 2.2 km^3, of which the volume of the ecological flood constituted 1.2 km^3 or 54% of the flood wave volume formed during the spring flood downstream of the DHC. The rather varied water flows here flatten towards the lower part, forming the favorable conditions for biodiversity development in this region.

2024. During winter and spring, water was accumulated in the Dnistrovsk res. in order to organize SEF. Two scenarios of its hydrograph were considered. According to them, the inflow was considered constant at 300 m^3/s, the initial level in the Dnistrovsk res. at 121 m. abs. and the volume at 2657 mln. m^3, the flood duration 21 days, and the peak flow 5 days. The peak flow according to the first scenario was considered 750 m^3/s, according to the second scenario 800-850 m^3/s. As a result of the ecological flood passage, its volume should be about 1 km^3, of which the volume compensated by the Dnistrovsk res. about 480 mln. m^3, the remaining volume would be about 2 km^3, and the remaining level about 118.3 m. abs.

The real situation showed that Ukraine organized the flood evacuation, which can be considered as a SEF, during the April 16 - May 1 period. In natural conditions, during the April 17-27 period, a very smooth fluctuation was formed with a peak flow of 362 m^3/s, average flow of 284 m^3/s, and volume of 265 mln. m^3. The shape of the flood hydrograph downstream of DHC was formed by the increasing and decreasing limb and two peaks. The flood evacuation from Dnistrovsk res. was carried out between April 17 – April 27. The evacuation peak flows from Dnistrovsk res. were 1116 m^3/s on April 18 and 1031 m^3/s on April 22. The flood volume was 640 mln. m^3, or 2.4 times more than that formed in the natural regime. The peak flows at Bender and Talmaza were within the limits of 860-905 m^3/s, being observed on April 21-22 and April 25-26, or with a delay of 3-4 days compared to the discharge from Dnistrovsk res. Compared to the SEF scenarios, the real situation showed that peak flows from Dnistrovsk res. were higher than those in the scenarios by 250-410 m^3/s, the flood volumes being lower by about 34%, the duration being relatively two times shorter compared to that proposed in the scenarios. The water level in the Dnistrovsk res. decreased from 120.2 m. abs. to about 117.6 m. abs., or by 2.6 m lower than proposed in the scenarios (about 50-60 cm) (Fig. 8).

Water temperature of the spring ecological flood. The average water temperature during the spring flood of 2023 was 7.7°C in the Dnistrovsk res., 8.3°C at Soroca, 9.7°C in the Dubăsari res., and 11-11.2°C from Criuleni to the river mouth. The daily temperature during the flood's first subphase was approx. 4-6°C in the Dnistrovsk res., variating from 8-9°C to 4-5°C and then to 6-7°C at Soroca. At Bender it was 7-8°C, rising to 9-10°C, at Talmaza it was lower, around 7-9°C. At Răscăieți, Tudora and Mayaki the temperatures exceeded 7.5°C, rosing to 10°C (Fig. 9).

The average water temperature during the ecological flood was 8.9°C in the Dnistrovsk res., 8.66°C at Soroca, 10.7°C in the Dnistrovsk res, the Dubăsari res. and Bender, and 11.9-12.7°C from Bender to the river mouth. The daily water temperature was characterized by increasing trends for the entire period, being 7-11°C in the Dnistrovsk res., 6-10°C at Soroca, 9-14°C in the Dubăsari res., 10-14°C at Bender and Talmaza, and 10-14.6°C at Tudora and Mayaki. During the spring flood passage and the ecological flood the favorable thermal conditions were formed for the development of fish and biodiversity in the Dniester River.

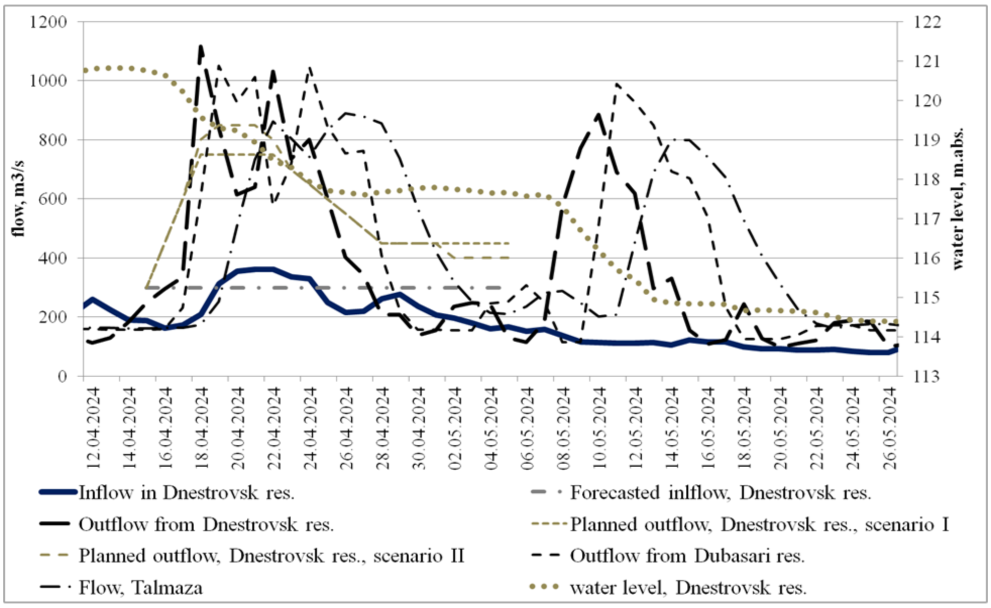

Figure 8. SEF 2024: scenarios and the real situation (built based on SHS MD and Ukrainian data).

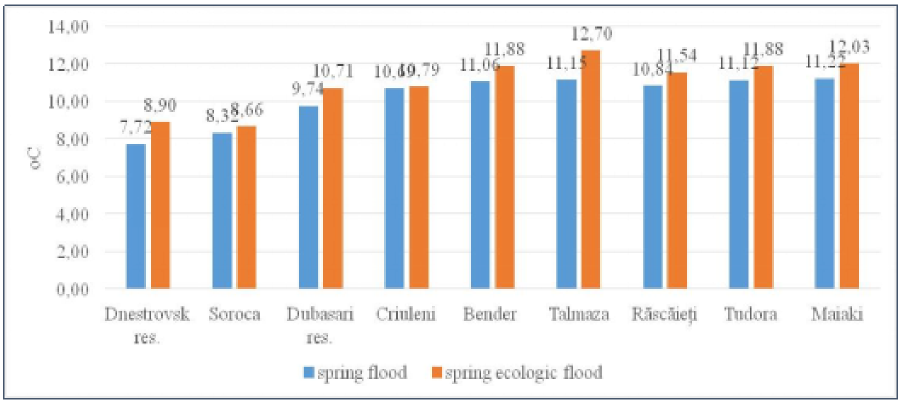

Figure 9. Average water temperature during the spring flood and SEF in 2023
(constructed based on SHS MD and Ukrainian data).

The average water temperature during the April 2024 flood was 12°C in the Dnistrovsk res., 8-9°C at the Naslavcea – Soroca sector, 12.8-13.7°C at the Dubăsari res. – Rascaieti sector and 15.3°C at the river mouth. At the beginning of the April flood, the water temperature reached high values of about 13°C in the Dnistrovsk res., 16-17°C from Dubăsari res. to the river mouth. During the same period, maximum air temperatures for April were also recorded, of about 18-20°C. However, in the following days and until the end of the April flood, the air temperature suddenly dropped to 8-9°C, and as a result the water temperature decreased to 11°C in the Dnistrovsk res., 10°C in Dubăsari res., 12-13°C at Talmaza – Răscăieţi and 14 °C Mayaki. At the Dubăsari res. – river mouth sectors the thermal decrease was on average 5°C, which significantly influenced the aquatic biota (Fig. 10).

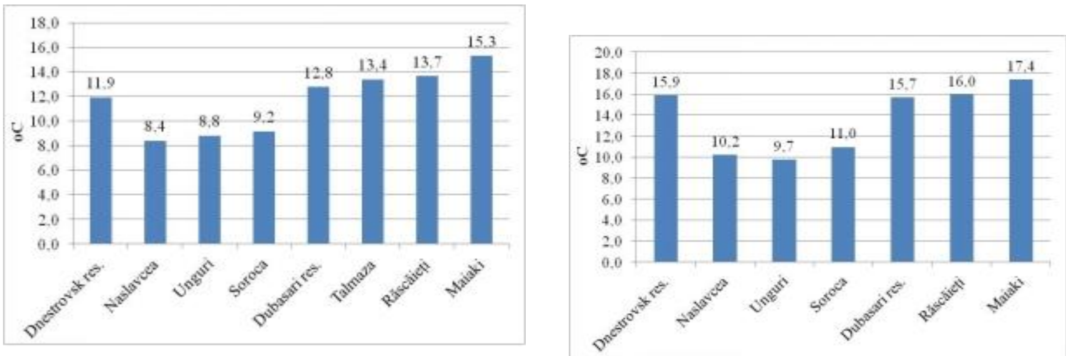

Figure 10. Average water temperature during the controlled flood propagation in spring 2024:
left – April flood, right – May flood (constructed based on SHS MD and from Ukraine data).

From the April flood ending to the peak flows of the next flood in May one, the air and water temperatures increased. At the beginning of the May flood, the water temperature reached 15-16°C in the Dnistrovsk res., 17-18°C at the Dubăsari res. - Mayaki section. During the decreasing phase of the May flood, the water temperature increased to 13-14°C in the Dnistrovsk res. and at the Dubăsari res. – Răscăieţi sector, and 16°C at Mayaki. Subsequently, the temperature was constantly increasing and reached maximum values towards the end of the analyzed period.

Flooded area in the Lower Dniester region. To assess the connection between water flow or water level and the potentially flooded area in the Lower Dniester Zone, the free Landsat satellite images for the period February – June 2024 were used. In total, six sufficiently clear and cloud-free images were identified, to be used for analysis. The images from February 27, March 29 and 30 and April 30 coincided with the floods decreasing phase. In the Bender – Talmaza sector, the peak flood flows were about 600-650 m^3/s in February, 700-750 m^3/s in March and 850-900 m^3/s in April. According to satellite images data, the water flows at the Talmaza station were about 270-570 m^3/s.

For comparison, the minimum areas covered by water were estimated through analyzing satellite images from the periods of minimum Dniester flows. These images coincided with April 14 when the flows was about 160 m^3/s and June 18 about 112 m^3/s. It should be emphasized that satellite images allow a high-accuracy assessment of free water surfaces; of rivers and lakes. Their use for determination of wetlands coverage is hampered by merging water and vegetation; respectively; the accuracy of establishing the boundaries of water covered areas is medium or even low.

The delimited area of the Lower Dniester Zone is 290 km^2. This area includes both Moldavian and Ukrainian wetlands. Based on satellite images, it was established that largest areas covered with water due to floods passage in the spring of 2024, were about 80-100 km^2. Monitored flows were over 270-570 m^3/s at the nearest flow station. Compared to the area of the study area, the share of the flooded zone in these periods was about 30% (Table 2).

Surfaces of about 28 km^2 covered by water during the low water period were represented by lakes practically permanently presented within the study area, covering about its 10%. As a result of accumulated information, the connection between water flows and water levels at the Talmaza post, Mayaki post and flooded areas of the Lower Dniester Zone was established. Such connection at the Talmaza post was about 52% and 61%, that is quite high. Much better connection was at the Mayaki station and the flooded area of the lower Dniester Zone (about 93%). The connections obtained can be used in the future to understand and assess the distribution of water in the Dniester River floodplain.

Table 2. Established flooded area, water level and flow.

Date	**Flow, m^3/s**		**Established flooded area, km^2**
	Dubăsari	Talmaza	
27.02.2024	245	316	97,8
29.03.2024	130	380	78,66
30.03.2024	184	272	91,65
14.04.2024	157	162	28,0
30.04.2024	158	569	88,5
18.06.2024	112	129	29

The largest lakes within the study area are Svine, Dragan, Kairo, Velika Huma, Krugle, Krive, Mikolaivka, Tudorove - between the Dniester and Turunchiuk, Byle, located at the confluence of the Turunchiuk branch and Dniester, Popove and Pohorile - near Bilyaivka, Davydove - near the customs point Mayaki - Udobne, Pisarske - near Iaske, Putryne - below the Kuchiurhan res. All lakes are connected to the Turunchiuk and Dniester branches by canals.

Analysis of cartographic materials of the past century, satellite images and own observations indicate the degradation of large sections of the Lower Dniester River. This degradation manifests itself in the reduction of spawning grounds, the overgrowth and reduction of water levels in floodplain lakes (Pisarske, Putryne, Byle, Svine, Krive, etc.), the swallowing or complete disappearance of connecting channels and streams with the lakes Pisarske, Safronove, Davydove, Babka, Mologa. Maps produced at the beginning of the last century and satellite images of the delta (Figs. 16-17) suggestive of changes have been occurred in the hydrological network of the Dniester Delta over the period from 1905 to the present.

Analysis of space images of large lakes water surface the delta showed that their area by 2023 had significantly decreased compared to them earlier (RUSEV, 2003), namely: Putryne from 220 ha to 132.93 ha, Byle from 130 ha to 93.68 ha (at the beginning of the last century about 300 ha), Pisarske from 70 ha to 30.12 ha. The area of Tudorove remained virtually unchanged. The image of the lake-flooded system adjacent to the northern part of the Dniester Estuary does not include Babka, Safronove and Davydove lakes and is among the spawning grounds of Common carp that don't migrate to spawn in the Dniester - Turunchiuk interfluve.

However, satellite images don't provide highly accurate information about flooded areas and don't allow estimating the water levels an important element during the fish reproduction period, and all biodiversity. It was a found clear link between the water flow and flooded Lower Dniester area. Figures 11-16 show the space images for different coverage of this area's wetlands under different water coverage in 2024.

Figure 11. Satellite image within the limits of the Lower Dniester Zone on 27.02.2024. Source: https://earthexplorer.usgs.gov/.

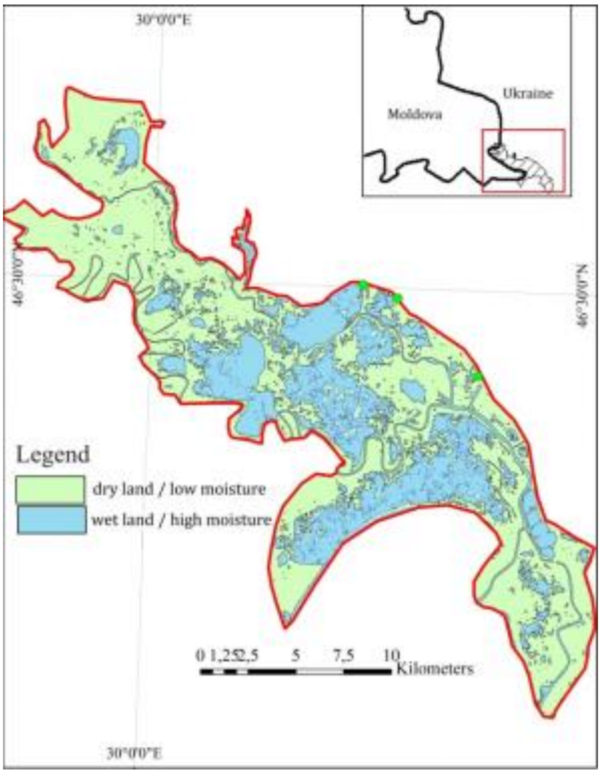

Figure 12. Potentially flooded areas within the Lower Dniester Zone on 27.02.2024.

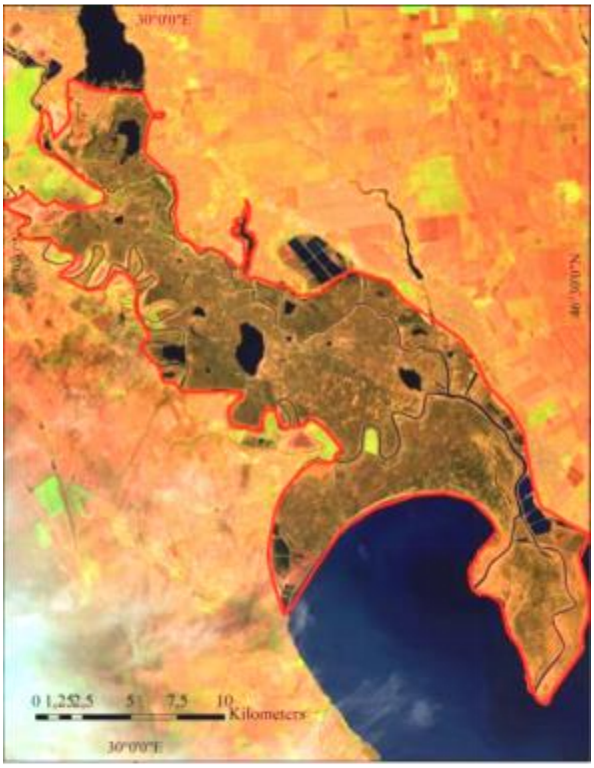

Figure 13. Satellite image within the limits of the Lower Dniester Zone on 30.03.2024. Source: https://earthexplorer.usgs.gov/.

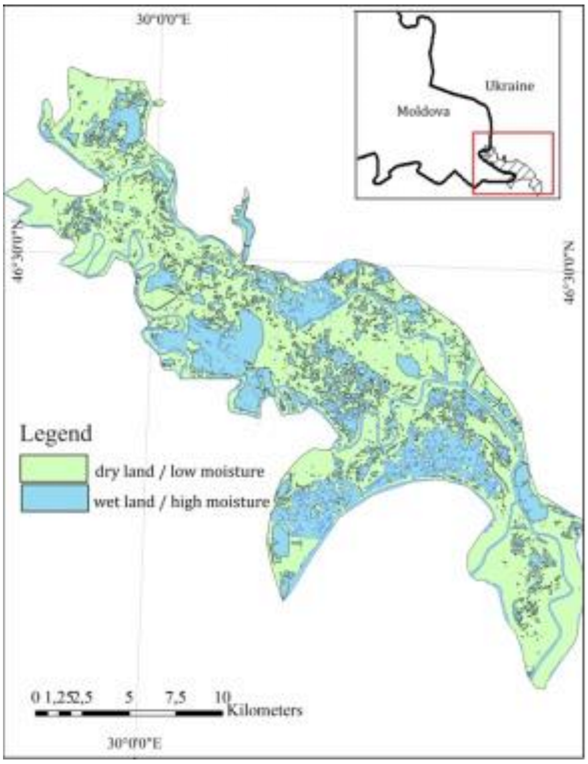

Figure 14. Potentially flooded areas within the Lower Dniester Zone on 30.03.2024.

Figure 15. Satellite image within the limits of the Lower Dniester Zone on 14.04.2024. Source: https://earthexplorer.usgs.gov/.

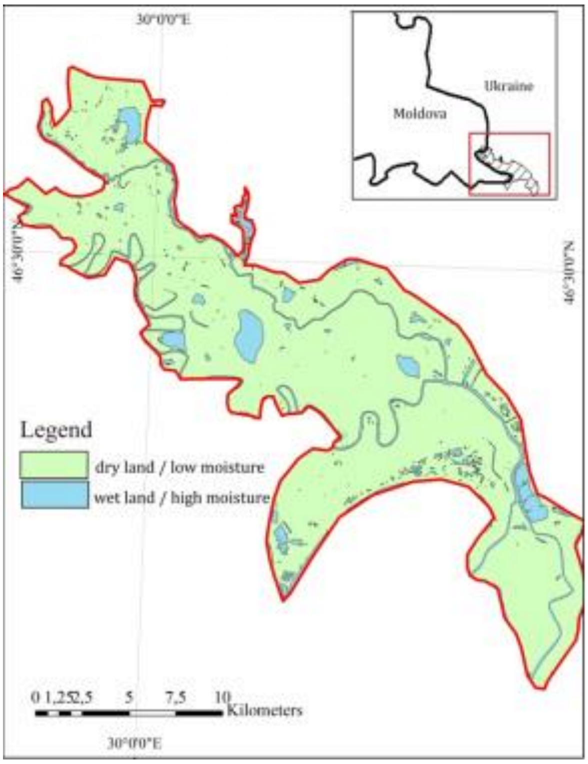

Figure 16. Potentially flooded areas within the Lower Dniester Zone on 14.04.2024.

Fish spawning grounds. Fish breeding sites in Moldovan part of the Lower Dniester are extremely varied. In most phytophilic fish, spawning usually takes place along the banks, in flooded riparian areas with relatively shallow depths. The choice of research stations in such areas of the Lower Dniester (within the borders of Moldova) was determined by the presence of spawning areas in various distant parts of the basin, as well as by hydroecological differences in these areas (water flow and its speed, the nature of their bottoms, sediments and substrates suitable for spawning, etc.). These spawning areas are located at the beginning of the former floodplain of a river, which is currently dammed in such a way the presence of flood-proof dikes during the high water period or spring ecological discharge does not substantially influence their flooding. They are located directly in areas adjacent to a riverbed and, in the case of overflows, extend only to the base of a flood dam or slope. Other areas of woodland are located directly in the riverbed, at various distances from banks. Since woodlands located at a greater distance from the riverbed are not flooded every year, they were not a subject in the present study.

The research has shown that in the Lower Dniester there are numerous reproduction sites, which are sufficiently favorable for fish with different reproductive biology.

Reproduction of phytophilic fish species under the Dniester conditions can take place in any suitable place, in shallow waters where there is soft herbaceous vegetation, but at the same time usually only a few specific locations are used for reproduction. In years with high flow, vast shallow areas are flooded, and the space suitable for reproduction sites increases significantly. A large number of islands and shoals have formed in the riverbed, and even fish that spawn early (Pike, Pike-perch, Perch) have enough places for spawning at low water levels.

The section from the Dubăsari res. dam downstream is directly influenced by the HPP operation. The upper part of this section (the 356-345 km) due to the high density of many fish species is considered a sensitive ecological area and is of great importance for the reproduction, fattening and wintering of fishes.

Changes in the Dniester hydrological regime as a result of flow regulation and non-compliance with water discharge regimes from reservoirs have a negative impact on the reproduction sites of the Lower Dniester, which has led to a reduction and deterioration of fish reproduction conditions in their areas Here, due to the embankment and drying up of most floodplains, the areas of spawning grounds have been greatly reduced, and therefore during an ecological flood it is important to make areas favorable for reproduction be flooded in a timely manner, so that fish can lay their eggs. However, most of spawning grounds either do not function due to the insufficient level of their flooding or serve as a trap for fish-spawners and fry due to sudden fluctuations in the water level.

In recent years, there has been a progressive degradation of large areas of the Lower Dniester floodplain in Delta, which is expressed in excessive overgrowth with terrestrial vegetation and the spawning grounds water surface reduction, the clogging or complete disappearance of water supply channels and a visible decrease in the flow and water reception capacity. The main causes of the floodplain woodlands degradation are:

- absence in recent years during January-February of a short-term discharge from the Dnistrovsk res. in volumes of 600-700 m^3/s for washing (sanitary discharge);
- clogging, drying and excessive vegetation overgrowth of channels/gullies that connect them to the Dniester riverbed;
- acceleration of natural succession processes in conditions of low river water levels;
- reduction in the volume of woodland rehabilitation works.

Important indicators of the efficiency of reproduction of phytophilic fish species in the Lower Dniester are the vastness/size and duration of flooding of spawning grounds. The spawning grounds area of the of phytophilic fish species in the 2022-2024 were flooded differently, depending on their location relative the river bed. The unprecedented operation regime of the Dnistrovsk HPP in these and previous years through significant fluctuations in the water level in the Lower Dniester negatively affected the status of riparian territories along the river here and the course of phytophilic fish species reproduction**.** A large part of previously important spawning grounds of the Lower Dniester are rarely completely flooded, only during extreme floods. The regime and duration of high water levels are very important especially in the areas of shallow bogs, especially those flooded and isolated from the main river bed. The large volume of river water and vast reversals causes water in shallow spawning grounds areas to warm up faster.

In the case of water shortage, a lower efficiency of phytophilic fish reproduction was observed due to the reduction of their access to spawning sites, the disruption of an egg maturation period and hatching of larvae and their post-reproductive migration to deeper places in the riverbed. As a result of the inconsistency of the DHC operation and the ecological requirements for the normal reproduction of fish ignoring, a rapid and repeated or premature decrease in the water level in the Lower Dniester and in the places of floodable spawning grounds often implicitly occurs. This leads to the death of the eggs, causes the fry the death, leads to a delay in the migration of spawners from depressions, pits and isolated spawning areas (Fig. 17). The fluctuations in the water level lowered the efficiency of reproduction some phytophilic fish species (Pike, Pike-perch, etc.) in some of the spawning grounds in riparian areas, and in some portions of the grounds with little water or isolated from the main streams of the basin; also, the eggs lost on vegetation and considerable mortality of larvae and fry were observed. The most disastrous effect is observed in species with one-time or short spawning most of the economically valuable species, in which in this situation the entire annual generation can be compromised.

Figure 17. Nests of Pike-perch - *Sander lucioperca*
(Delacău – Şerpeni section, 12-15.04.24, 157-159 m^3/s, 15-16^oC).

During 2022-2024, a total of 39 fish species were identified in the Lower Dniester River from the Dubăsari HPP dam to the Tudora village, belonging to 34 genera and 9 families: Clupeidae – 2, Cyprinidae – 22, Cobitidae – 1, Siluridae – 1, Esocidae – 1, Syngnathidae – 1, Centrarhidae – 1, Percidae – 2 and Gobiidae – 8 species. Among the phytophilic fish species, the most widespread and numerous were Crucian carp, Roach, Bream, Bleak, Rudd, and Perch. Of these, initially Pike and Perch dominated in succession, and later – Roach and Crucian carp.

The achievement of sexual maturity and the first spawning do not occur in all fish in the same year of their life. There is a wide amplitude in this regard – from several months in some species to many years in others. On the other hand, there are many fish that mature very early. Fish of the same species often become sexually mature at different ages. Some individuals reach sexual maturity earlier, others later. In this case, the time of sexual maturation depends on nutritional conditions: the better the nutrition, the faster the fish grows and the earlier it becomes an adult. Moreover, even in the same water body, for the first time fish becomes sexually mature at different ages.

In the Lower Dniester an earlier maturation of some fish species was noted. Thus, the male Bream with a length of 13-17 cm and at 2 years age were already mature (stages IV-V), and the females were immature. The 2-year-old Big-eye Bream and 15-19 cm long were preparing for spawning (stage IV of maturation). Also, the male Big-eye bream with a length of 12-14 cm and females with a length of 12-12.5 cm were also prepared for reproduction (stage IV of maturation). The same thing can be observed in the populations of other phytophilic fish species.

In the Ukrainian section of the Dniester Delta in 2024, spawning of Roach, Pike-perch and Perch began in March and practically ended in mid-April. The Bleak spawned during April and the first half of May. The spawning of Common carp in 2022-2023 started in the first decade of May, but in 2024 in the Ukrainian section of the Lower Dniester took place at the same time as the spawning of Crucian carp and in warmed shallow waters of the delta was noted during April - early June. Aged Common carp weighing 10-15 kg were spotted in April 2024 in a flooded floodplain spawning grounds near the village Troitske at the beginning of April. Typical spawning grounds are presented at Figs. 18 and 19. According to the results of observations in the Ukrainian section of the Lower Dniester in 2024 Pike spawning ended in March, long before the ecological flood started. Common carp spawning took place from the first April ten days beginning to the first ten days of June, with stops in cold periods.

The results of an obtained analysis on the status of seminal products (their degree of maturation) demonstrate that it is possible to establish the terms of the onset, intensive course and end of reproduction of main species of phytophilic fish, allowing to highlight the optimal moment of starting the spring ecological discharge, provided that there are no atmospheric anomalies that would cause a decrease in the water temperature in shallow waters. Our observations indicate that for most valuable species of phytophilic fish, the optimal temperature for efficient reproduction is 14-18°C. But the intensive reproduction of other species of phytophilic fish is triggered when the water temperature in the riverbed downstream of the Dubăsari HPP reaches at least 12-13°C. In fact, these results correspond to those obtained by other researchers in the field.

Figure 18**.** Lake Male Byle – the place of spawning of Common carp and Crucian carp (May 27, 2024).

Figure 19. Wetland near Bilyaivka town - spawning ground of Crucian carp (May 08, 2024).

The process of fish reproduction in each specific year undergoes very significant variations under the influence of abiotic and biotic factors in the spawning grounds (flow, current, level, temperature and oxidability of water, aeolian regime, wintering conditions, the size of the stock of parent fish, the numerical strength of different generations of fish, fishing intensity, etc.). The duration of a maturation period, incubation of eggs and hatching of larvae even within the same fish species differs and depends on changes in various environmental factors, especially temperature and water level.

Many fish species use the same spawning grounds in different periods, which allows for a more efficient use of substrate and food resources, thus mitigating interspecific competition relations. For example, roach and bream spawn in the same quality of water, but roach eggs develop earlier and at lower water temperatures (12-16°C) and are mainly attached to last year's dead vegetation, while roach eggs develop later and at higher temperatures (15-18°C) and are attached to plants in full vegetation.

Thus, depending on the thermal regime in the Dniester River, the first to begin reproducing are Pike (6°C), Pike-perch (9-13°C), then Bream (14-16°C), Crucian carp (13-20°C) and Common carp (13-20°C). In this situation, an successful penetration into shallow spawning grounds is especially ensured.

In 2022-2024 it was observed that the start of ~~a~~ reproductive period of Roach, Pike, Bream and Pike-perch in the Lower Dniester River took place in calendar terms later than usual, which caused the shortening of the development period of the fry and their entry into an unsatisfactory physiological state during wintering.

Tables 3-8 present data on the beginning and duration of reproduction in the analyzed species of phytophilic fish in the spring of 2022-202, depending on the water temperature. According to our observations, the range of spawning temperatures in the Lower Dniester in 2022 was between 12°C and 23°C, while during the maximum spring discharge the water temperature ranged from 9°C to 12°C. The reproduction of Common carp, Bream and Crucian carp began relatively late, and the reproduction of Bream began on usual terms – on April 10 (Table 3).

In the spring of **2023**, in the riparian spawning grounds and Dniester Delta (within the borders of Moldova), intensive reproduction of Common carp was observed in the first quarter of May, at a water temperature of 13-14°C, but the massive reproduction of most phytophilic fish species began after it reached 18°C.

Table 3. Data on the terms of the main phytophilic fish species reproduction in the Lower Dniester, 2022.

Species	The beginning of reproduction / water temperature	River section	Spawning duration
Esox lucius	22.03 / 4ºC	Downstream of Dubăsari HPP	1-2 weeks
Perca fluviatilis	02-11.04 / 10.5ºC	Lower Dniester, Purcari - Olăneşti	1-1.5 weeks
Sander lucioperca	15.04 / 12ºC	Ustia - Dubăsarii Vechi	1-2 weeks
Alburnus alburnus	26.04 / 18ºC	Lower Dniester	3-6 weeks
Rutilus heckelii	10.04 / 11ºC	Lower Dniester	1-2 weeks
R. rutilus	26.04 / 12ºC	Ustia, Talmaza	1-2 weeks
Ballerus sapa	14.05 / 18ºC	Talmaza – Cioburciu	1-2 weeks
Aramis brama	15-16.04 / 18ºC	Dubăsari HPP – Speia	2-3 weeks
Blicca bjoerkna	10.05 / 14.8ºC	Lower Dniester	Delayed spawning, 3-4 weeks
Carassius auratus-complex	01-06.05 / 16.5ºC	Lower Dniester	Delayed spawning, 3-6 weeks.
Cyprinus carpio	10-13.05 / 20.5ºC	Ustia – Şerpeni, Talmaza	Delayed spawning, 2-3 weeks

Compared to water discharge in 2022, in the spring of 2023, despite the water temperatures in Dniester were lower in late April - early May, it was more effective for fish reproduction. This was due to the larger flooding of spawning grounds and longer time of maintaining the water level in them. In spawning grounds of the Purcari-Tudora section on May 06, the reproduction of Common carp and Crucian carp was observed during this period. Simultaneous reproduction of these two species was observed during the first quarter of April and continued with little intensity until the first quarter of June. The number of Crucian carp at the observation points was higher than that of Common carp. In May-June, only low-intensity reproduction of Crucian carp was recorded in these spawning grounds downstream of the Lower Dniester. Reproduction of Bream was not observed, since shallow waters of 20-30 cm are not suitable for this species. It can be said the conditions for reproduction in 2023 were not relatively optimal, and its efficiency was reduced (Table 4).

Table 4. Data on the terms of reproduction of the main phytophilic fish species in the Lower Dniester, 2023.

Species	The beginning of reproduction	Spawning duration
Esox lucius	09-15.03	1.5-2 weeks
Sander lucioperca	10.04	1-2 weeks
Perca fluviatilis	04-12.04	1-2 weeks
Abramis brama	20.04	1 week
Rutilus spp.	20.04	1 week
Carassius auratus-complex	03.05	Delayed spawning, 3-6 weeks
Ballerus sapa	07.05	1-2 weeks
Cyprinus carpio	09.05	2-3 weeks
Blicca bjoerkna	10.05	Delayed spawning, 3-4 weeks
Alburnus alburnus	12.05	Delayed spawning, 3-6 weeks

In 2024 the conditions for the reproduction of phytophilic fish were aggravated (Table 5). At the beginning of April, a rapid atmospheric warming was observed and by April 10 the water temperature in the Lower Dniester increased to 14.8°C (which is about 7°C higher than on the same date in 2023) with a subsequent continuous increase. This year the start of the reproductive campaign in phytophilic fish (Pike, Bream, Roach and Pike-perch) took place calendaristically later than usual, which caused the shortening of the development period of the fry and their entry into wintering in an unsatisfactory physiological state.

The reproduction of the main valuable species of phytophilic fish in the Lower Dniester basin was relatively early and prolonged due to variations in water temperature. Their reproduction took place in the first quarter of May. In March and April, the efficiency of reproduction was low due to the onset of low temperatures during the period of high flood. The water level in the floodplain spawning grounds in April-May fluctuated quite a lot, as a result reproduction in these places did not took place very efficiently. Compared to average multi-annual terms of reproduction of the main phytophilic fish here (BULAT et al., 2014; MUSTEA & FILIPENCO, 2022), the beginning of reproduction period in 2024 shifted by about 7-10 days earlier. But under the conditions of atmospheric warming from the beginning of April, the reproduction took place within the normal temperature range for these fish species (Table 5). At the same time, under these conditions, the reproduction took place within the normal temperature range for these phytophilic species. In the riparian areas of flooded spawning grounds, significant fluctuations in the water level in April could not ensure the survival of laid eggs and, implicitly, led to their death after a serious temperature drop on April 19.

The decrease in the volume of discharges led to a significant decrease in the reproductive efficiency of Crucian carp and Common carp. Due to the low water temperature, the intensive reproduction of these fish was reduced during this period, which affected its efficiency. However, species with portioned reproduction (Crucian carp, Common carp, White bream, Rudd, European catfish) were able partially compensate for these losses by continuing to reproduce in the second half of April and in May in the lower areas that remained flooded.

Pike reproduction ended in March, long before the start of an ecological flow. Reproduction of Bream, Roach, Pike-perch and Perch began in March (before the start of observations) and ended in mid-April. Common carp reproduction took place from the beginning of the first quarter of April to the first quarter of June. The reproduction of Crucian carp also began in the first quarter of April and continued with little intensity in the first quarter of June. The reproduction of Common carp and Crucian carp was partially disturbed by fluctuations in the water level. For Crucian carp and Common carp, the reproduction conditions were more satisfactory a large number of larvae were observed in the spawning grounds. The reproduction of Bream lasted throughout April and until the first half of May.

According to observations from previous years, during the mass reproduction period of Bream and Roach, the water temperature in the Lower Dniester riverbed does not exceed 8-10°C, and in flooded riparian areas or shallow lakes during the same period the water warms up to 16-18°C.

Disturbances in the thermal regime (low temperatures in the spring early summer period and high temperatures in the autumn-winter periods) downstream of dams cause various dysfunctions in the vital cycles of hydrobionts, and at the cellular level in the process of gametogenesis. The most common changes in the reproductive system of fish are: asymmetric development of the gonads, their atypical shape, changes in the duration of oogenesis and spermatogenesis, cases of mass resorption of gonads' cells in the last stages of trophoplasmic growth, reduction of egg portions and decrease in prolificacy, disorders in the process of vitellogenesis, decrease in fertilization capacity, decrease in the weight of individuals capable of reproduction, abortion of eggs due to damage to the follicular membranes, etc. (CEPURNOVA, 1991).

Table 5. Terms of reproduction of main phytophilic fish species in the Lower Dniester (Dubăsari HPP – Tudora village) in 2024.

Species	Optimal water temperature, °C*	Real water temperature, °C	The beginning of reproduction	Spawning duration
Esox lucius	8-12	7-10	01-05.03.24	2-3 weeks
Perca fluviatilis	9-12	10-13	10.04.24	1.5-2 weeks
Sander lucioperca	12-14	11-14	18.04.24	1-2 week
Rutilus spp.	12-14	13-15	15.04.24	1-2 weeks
Abramis brama	14-16	14-16	16-25.04.24	1-2 weeks
Carassius auratus-complex	15-18	14-18	05.05.24	Delayed spawning, 4-6 weeks, and later
Ballerus sapa	14-16	13-15	05.05.24	1 week
Blicca bjoerkna	16-17	16-17	06-09.05.24	Delayed spawning, 3-4 weeks
Cyprinus carpio	16-20	16-20	01-05.05.24	1-2 weeks
Alburnus alburnus	16-18	15-17	10.05.24	Delayed spawning, 3-4 weeks

* The optimal temperature values for reproduction vary depending on the particularity of the fish populations of the species, the characteristics of the spawning sites and the meteorological conditions of the each year. Without brackets – values characteristic of the region (Dniester River).

This thermal and water level influence downstream of the HPP causes various dysfunctions in the vital cycles of hydrobionts and at the cellular level in the process of gametogenesis. As a result of unfavorable conditions (water shortage, spawning substrate, low temperatures), in many fish species (and primarily Common carp) in the spawning grounds during this period, the resorption of seminal products (destruction of the membranes in the eggs) could be observed, which in turn could cause their subsequent death. Among the dead fish with signs of resorption were sexually mature individuals of Common carp, Crucian carp, Bream, Breamflat and Roach. Dead individuals of the listed fish were found mainly in the shallow spawning grounds of floodplain lakes and in smaller numbers – in the coastal areas along the Dniester course. Unfavorable conditions during the fish reproduction period can cause disruptions in gametogenesis and, respectively, change the timing of spawning.

The reproduction of phytophilic fish in the 2022-2024 also took place in the case of low water level, with use of spawning unsuitable substrates available in shallow places in the riverbed (hydrophytes, tree roots and shrubs); however, it is obvious that reproduction was not as successful as in flooded riparian macrophytes. The deficit of suitable spawning grounds due to their incomplete flooding led to a situation when reproduction of Pike took place directly in the riverbed. In addition, the reproduction of Roach, Bream, White-eye Bream and Bleak took place not in floodplain meadows with well-warmed water, but in the coastal areas and in gullies among hydrophytes, tree roots and other natural substrates.

Observations have shown that spring river overflows stimulate reproductive activity and gonad maturation only in the case of a gradual increase in water temperature, while the increase in water level in the swamp areas does not lead to the mass triggering of fish reproduction without water warming to the optimal values for each species. The hydrometeorological situation in the Lower Dniester in April-May 2022-2024, as well as the implementation dates and parameters of spring spawning ecological floods were characterized by noticeable differences. One of the most important factors determining the numeric strength of the spawning stock is the volume of water in a river. It is known (NIKOLSKY, 1974 and own observations) that for many fish the signal and stimulus for the beginning of reproductive migration, concentration in the spawning grounds and spawning is the increase in water level and a certain value of water temperature (depending on the species or their ecological group) and the extensive flooding of spawning areas. An increase in water level and flows and their longer maintenance during the reproductive migration of fish, which would coincide with the spring flood, can stimulate the arrival of an additional number of adult individuals, as well as contribute to the survival of eggs and fry.

In addition to a such determining factors for the timing and course of fish spawning as temperature, the level of water in the river which depends on the filling of floodplain and coastal spawning grounds, is equally important. At the same time, if at least 800 m^3 is required for the flooding and filling of floodplain spawning grounds, then for the functioning of coastal spawning grounds the necessary discharge volume may be smaller. More important is its consistency (duration of at least 5 days with appropriate water temperature), which allows effective spawning. Otherwise, as a result of the rapid drop in a water level, the death of eggs occurs on exposed coastal spawning grounds.

Delta is densely overgrown with reeds and in the absence of clearing it cannot be used as a spawning ground, as it is not accessible to fish. The water coverage of Delta – the biggest part of spawning grounds in the Lower Dniester, significantly fluctuated (see an example in Fig. 20). Fluctuations of water level in Dniester floodplain in 2024 depended from Dubăsari res. discharges and periodically dried, which negatively influenced on fish reproduction.

Figure 20. Calculated dynamics of changes in the flooded area of the floodplain massif between the Dniester River and Turunchiuk branch for the period from February to the first half of July 2024 (personal information of Oleg Hryb, Odessa).

DISCUSSION AND CONCLUSIONS

The need to simulate a spring flood of a river to promote the reproduction of phytophilic fish species arises where the hydrological cycle is disrupted by dams. At the same time, to successfully carry out this flood, there should not be many dams on the river. In addition, hydropower engineers are usually not interested in carrying out a SEF, so it can only be carried out where the environmental lobby is strong enough. Such situations are quite rare, and apparently, therefore, the Dniester has become almost the only river in the Black Sea basin where such a practice is used.

After analyzing the hydrological situation in the Dniester River basin, including flooded areas, in the period of spring natural and ecological floods based on satellite images, meteorological situation and current climate trends, the following evidences and characteristics are discussed:

- The shape of the hydrograph – trapezoid, the increasing limb being short (4-5 days), while the decreasing one – longer (over 10 days), the period of peak flow – more than 7-10 days, the total duration of the food should exceed 25-30 days.
- The DHC peak discharge flow must exceed 700-800 m^3/s, taking into account the spawning grounds located in the Dniester riverbed within Moldova, however flooded areas remain quite small even in this case. The values of these flows often decrease towards the floods lower part, their waves being subjected to flattening processes, although still covering by water sufficient areas for the development of aquatic ecosystems, especially fish, in the Lower Dniester Zone.
- The water volume in the Dnistrovsk res. available for SEF should exceed 1 km^3 and must be accumulated starting in December. As a result, its water level should reach about 121 m abs. or maybe slightly exceed this value but

not more than 122 m. abs. As a result of the water discharge for an ecological flood, its level in the reservoir should not be lower 116.5-117 m abs. to guarantee water volumes for the summer period. These parameters have to be reflected in the Operational Rules (2022).

- The period of initiation an ecological flood for the Lower Dniester should be mid-April - May, depending on water temperature and fish readiness for reproduction.
- In case of favorable hydrological conditions, it is recommended to organize fluctuations or washing floods in the period preceding an ecological flood by one/two months, but also to organize ecological floods in June – July to favor the development of fish in these periods, especially fish in the DHC–Sănătăuca river sector – an area subject to maximum impact of DHC. Within this sector, water temperatures favorable to fish development are delayed due to thermal effects caused by the Dnistrovsk reservoir operation.

The diversity of hydrological characteristics in the spring period allows the establishment of three classic situations:

1. The low flows during winter and spring, fluctuations/small spring high waters with formation in January – March. In this case it is recommended to accumulate progressively water in the Dnistrovsk res. up to 121 m. abs. (or a little more) by April – May, with its subsequent evacuation as an ecological flood.
2. The better hydrological conditions, with the manifestation of spring floods in the period March - May allowing the good organization of an ecological flood with the above mentioned parameters.
3. The formation of small fluctuations/floods in the winter period, but also the manifestation of spring floods in the spring period, which allows the organization of washing as well as ecological floods both in spring and summer periods.

For the SEF proper organization it is necessary:

- to clearly establish the interests of stakeholders interested in an ecological flood: the needs of the aquatic ecosystems in the Dnistrovsk res., the aquatic ecosystems in the Lower Dniester the ecosystem needs within Moldavian borders;
- ensuring the short-term hydrological and meteorological forecasts;
- efforts to improve long-term meteorological and hydrological forecasts, because in the conditions of water shortages that may occur in the summer period, the water accumulated in the winter - spring period must be saved for it providing for population during a potentially dry period;
- to strengthen Moldova-Ukraine cooperation for optimizing the planning processes on SEFs and improve hydrological situations in the spring; in this regard, in the flood period the frequency of communication between representatives of Moldova and Ukraine must increase;
- the evacuation scenarios of SEFs must be developed and approved by experts from both states, which should include the parameters of these floods described above;
- the DHC Operation Rules should include clear regulations on water accumulation during the winter period to ensure the organization of SEFs evacuation, as well as clear rules for these floods organization;
- to identify priority ecosystem services for which a SEF is organized, including needs to expand, arrange, and protect fish breeding areas (the Dniester bed, Dubăsari res., Old Dniester, wetlands, etc.) and ensure optimal conditions at local and regional levels to achieve desired goals (stocking/restocking with fish, banning fishing during specific periods, combating poaching, cleaning the areas where the ecological flood water passes, etc.).

To improve the natural reproduction conditions of main phytophilic fish species in the Lower Dniester, the following measures must be applied:

- The decision on the period and parameters of a SEF has to be taken based on the hydrometeorological situation, the water volumes existing in Dnistrovsk res. and a hydrological forecast.
- The refuse from carrying out the short-term discharges from the Dnistrovsk res. with a maximum flow of 300-400 m$^{3/}$s and a flow rate of over 75% of water supply, as they do not ensure the water level required for flooding the spawning grounds and maintaining it downstream of the Lower Dniester. This issue should be reflected in the DHC Operational Rules (***. ORDER, 2022).

The hydrograph of the flood, regardless of its volume, must ensure:

- the consecutive increase in a water volume from the beginning of its discharge in order to flood the spawning grounds for at least 5 days; maintaining the water level in spawning sites by stabilizing the volume of discharge from both reservoirs ensuring reproduction, incubation of eggs and development of larvae up to the fingerlings stage at least 25 days;
- the minimum volume during the discharge peak period at least 400 m^3/s;
- gradual reduction of discharge volumes by 50 m^3/s per day for 5-6 days, depending on the degree of spawning grounds flooding.

As an effective SEF for hydrobiocenosis is considered when the volume of the discharged flow from the Dnistrovsk res. exceeds 1 km^3 for month, taking into account the comfortable thermal conditions for fish reproduction. For sufficient flooding of spawning grounds ~~of~~ in the Lower Dniester, including the Turunchiuk branch, an ecological flood is necessary at a volume of 800 m^3/s; for riparian spawning grounds a volume of 600 m^3/s is sufficient. During the later stage of a phytophilic fish reproduction period at temperature in spawning grounds 16-18^{o}C the ecological flood should be maintained at a level of 400-450 m^3/s - this is the minimum volume ensuring sufficient flooding of phytophilic fish spawning grounds.

The period of ecological floods (beginning, course and end) must coincide with both the moment of migration and reproductive concentration of fish, taking into account a time necessary for reproduction and hatching of larvae and their transition to exogenous food (about 5-7 days, depending on water temperature), as well as the moment when the fry emerge from the spawning grounds to deeper places (in case the spawning grounds are not located in the riverbed).

Taking into account the time for water arrival from the Dnistrovsk res. and the tendency of increasing its temperature in the Lower Dniester, the ecological flood should begin in the first or second decades of April at a water temperature of at least 12ºC at Dubăsari gouging station, with the forecast for further warming.

The involvement of Dubăsari HPP as an additional regulator of the ecological flood volumes from the Dnistrovsk res. by increasing them in extreme situations would be useful for the reproduction of fish different ecological groups. However, the decision on the Dubăsari res. participation in regulating of ecological flood volumes requires additional coordination with the HPP administration and, obviously, amendments to the Regulations for this reservoir exploitation.

It is recommended to include the following provisions in the DHC Operation Rules (***. ORDER, 2022) when they are revised:

1. In the presence of appropriate hydrometeorological conditions during the winter and spring, to ensure that water accumulates in the Dnistrovsk res. to a level of 120.5-121 m or even more by the end of March for its use during the spring ecological release in April and May;

2. The hydrograph of the spring ecological release established by both parties is correlated weekly based on forecasts of the meteorological and hydrological situation.

Thus, under the existing conditions, created in the result of climate change, any ensuring high and long-term discharge flows required during the period of optimal water temperatures in the main fish spawning areas of the Lower Dniester is practically impossible. The multi-annual decrease in the average annual discharge of the Dniester and the increase in Ukraine's needs for hydropower could affect the operating regimes of the DHC and the volumes of ecological floods from the Dnistrovsk res. to the downstream Dniester ecosystems. Due to the critical state of the energy complex in Ukraine caused by the destruction of energetic facilities during Russian aggression, there is a high probability that in the next several years the priority in developing the regime of the DHC operation will be ensuring energy security, and not the environmental needs of the Lower Dniester, using water of the Dnistrovsk res. mainly for energy production in winter and early spring. In these conditions, the role of correctly organized SEFs rises extremely.

The meteorological elements in the three years analyzed are within the long-term trends of increasing air temperatures and decreasing precipitation at all hydrometeorological stations of the research target area.

The average air temperature in the spring period during the 3 years of analysis is characterized by exceeding the thermal norm. During spring 2022, the excess is by 0.7-2°C, spring 2023 - about 0.85°C, spring 2024 - about 2.8°C. The increase in the average spring temperature above the norm for all three years analyzed is influenced, in particular, by the high temperatures in March. The average air temperatures in April in 2022 and 2023 are slightly below the thermal norm, while those in April 2024 exceed the norm by about 2°C for the entire Dniester basin. The month of May is characterized by thermal values close to the norm for the entire Dniester basin.

To include the ichthyological parameters to the set of conditions of ecological flood, investigations carried out in the Lower Dniester section were realized, which allow us to draw the following conclusions:

- The hydrometeorological situation in the Dniester River basin in the spring of 2022-2024, as well as the terms and parameters of ecological discharges, were characterized by visible differences. In 2022, the ecological discharge began too early, was small by volume which did not provided favorable conditions for the reproduction of phytophilic fish. The ecological discharge in the spring of 2023, despite the low water temperatures in mid-April (10-11.7˚C), was more effective than in 2022 due to the more extensive flooding of riparian spawning grounds. In 2024, due to the critical energy shortage in Ukraine, the ecological discharge parameters were not respected, the volumes of water discharges from the Dnistrovsk res. were adjusted daily according to the needs of the energy system, which led to significant fluctuations in the water level in the lower reaches of the Dniester in March and April - the period of the beginning of the reproduction of phytophilic fish.
- The analysis of multi-annual data on the implementation of ecological floods by the Dnistrovsk res. shows that the actual regimes of a part of the floods for various reasons (small volumes, short duration, early triggering, violations of the release schedule, etc.), usually did not provide favorable conditions necessary for the efficient reproduction of most phytophilic fish species in the Lower Dniester, it being low. It can be stated that of the three years (2022-2024), the most favorable for the efficient reproduction of phytophilic fish in the Lower Dniester was the ecological flood regime in 2023. Thus, the reproduction conditions for phytophilic fish species in the Lower Dniester in the spring of 2022 were unfavorable due to the low water level and temperature fluctuations, and fish reproduction was ineffective throughout the period of seasonal prohibition. Reproduction of phytophilic fish in 2023 did not coincide with its optimal temperatures (13-18°C – May) or with satisfactory discharges (over 400 m^3/s). However, the breeding conditions for phytophilic fish species in the Lower Dniester in the spring of 2023 were slightly better than those in 2022, due to the high water level and the development of the ecological flood hydrograph. The Dniester flow from April 10 to May 09, 2022 was 0.54 km^3, but in 2023 the flow from April 12 to May 11 was 1.6 km^3. However, the weather conditions were unfavorable due to low atmospheric temperatures and their fluctuations in April, which negatively

affected the effectiveness of reproduction. The hasty decision to start the spring ecological discharge in 2023 earlier than initially adopted, caused an unnecessary water discharge, when the fish were not yet physiologically ready for reproduction due to low temperatures. Therefore, if there had been a truthful weather forecast, it is obvious that the discharge should have started a little later – at the beginning of the last trimester of April. The conditions for the reproduction of phytophilic fish species in the Lower Dniester in the spring of 2024 (except for Common carp and the first spawning of Crucian carp) were more unfavorable, compared to those in 2023, as a result of the low water level, implicitly the reduced flooding of the riparian spawning grounds, as well as the organization of the main ecological flood (peak) during the period of low water temperatures. The unfavorable weather conditions due to low atmospheric temperatures and their fluctuations in April had a negative impact on the efficiency of reproduction.

In terms of spawning time, depending on the temperature regime of the river, the first to spawn are Pike (6°C), Bream (13-15°C), then Crucian carp (14-18°C) and Common carp (14-20°C), which allows for more efficient use of spawning grounds, mitigating competitive relations among the main commercially valuable fish species. For the main commercially valuable phytophilic fish species of the Dniester, the optimal temperatures for successful spawning are 14-18°C. Based on this, the ecological flood must be carried out not with reference to the calendar schedule, but to the water temperature in the Dniester River, which should be about 12-13°C. So, the beginning of the ecological flood should be established taking into consideration weather forecasts with the perspective to reach water temperature 14°C in 7-10 days.

In addition to such a determining factor for the timing and course of fish spawning as temperature, no less important is the water level in the river, on which the filling of floodplain and coastal spawning grounds depends. Moreover, if a release volume of at least 800 m^3/s is required to flood and fill the floodplain spawning grounds, then for the functioning of coastal spawning grounds the required release volume may be less, but its constancy is more important, which allows the fish to spawn effectively. Otherwise, as a result of a rapid decrease in the water level, the eggs die in the exposed coastal spawning grounds.

The floodplain spawning grounds were flooded to varying degrees (depending on their location to the river bed), which allowed phytophilic fish species (Common carp, Crucian carp, Bream, Roach) to spawn in them. A large number of fry were noted in the floodplain spawning grounds. After spawning, the water level dropped, which led to the isolation of the floodplain spawning grounds and the death of the young fish. Another flood is needed in July to ensure the exit of young fish from spawning grounds into the Dniester riverbed. The hydrological regime of the Dniester in 2022-2024 excluded this possibility.

Under the existing conditions, created in the result of climate change, ensuring high and long-term discharge flows required during the period of optimal water temperatures in the main fish spawning areas of the Lower Dniester is practically impossible. The multi-annual decrease in the average annual discharge of the Dniester and the increase in Ukraine's needs for hydropower could affect the operating regimes of the DHC and the volumes of ecological floods from the Dnistrovsk res. to the downstream Dniester ecosystems. Due to the critical state of the energy complex in Ukraine caused by the destruction of energetic facilities during aggression of the Russian Federation, there is a high probability that in the next several years the priority in developing the regime of operation of the DHC and ecological floods will be ensuring energy security, and not the environmental needs of the Lower Dniester, using water of the Dnistrovsk res. for energy production in winter and early spring. In these conditions, the role of correctly organized SEFs rises.

The status of the main fish populations in the eve of the ecological flood should be taken into consideration during development of the hydrograph. The fish gonads of Common carp, Crucian carp, Rudd, Roach, and Bream should be on the IV-th stage of maturation. Such ichthyological monitoring in the March-May period is need to be financially supported in both riparian states, to develop an optimal hydrograph and to propose the fishery ban period for concrete year.

ACKNOWLEDGEMENTS

The current research was produced in the frame of the UNDP Moldova project Nr. 10078766 “Carrying out the Dniester River spring ecological release optimization study”, financially supported by Sweden and implemented by the International Association of River Keepers “Eco-TIRAS”. The authors thank UNDP and Swedish people for such opportunity.

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Received: April 15, 2025
Accepted: August 03, 2025