Reproductive potential of yellow water-lily (\textit{Nuphar lutea}) in the conditions of lake ecosystems

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	extit{Nuphar lutea} (L.) Sm. (Nymphaeaceae Salisb.) belongs to the category of highly active cenose-forming plants in water bodies and water flows. The material for study of morphological peculiarities and seed productivity of the fruits of this species was collected mainly in the lake ecosystems of the Central Part of European Russia and Republic of Belarus. In the study we used biomorphological and ontogenetic approaches. Seed productivity was surveyed by direct count of number of seeds in the fruit. By abundance (in descending order), the significant reliable inter-lake differences in a number of morphological parameters of the fruit fall into the following sequence: number of rays of stigma of fruit (in six pairs of lakes) > length of fruit (in four pairs of lakes) > diameter of the stigma of fruit (in three pairs of lakes) > diameter of fruit (in two pairs of lakes) > length of the neck of the fruit (in one pair of lakes). Intra-regional differences in certain morphological parameters of fruits (by number of rays of stigmas) were most notably manifested only in the Belarus lakes which are similar by trophic status. All the differences in the fruits’ morphology could be due to differences in the habitat by the amount of nutrients in water and soil. The amount of seed productivity of the fruits from \textit{N. lutea} varies broadly. Analysis of this parameter depending on the character of soils in which the plants grew indicated reliable results only in the case of muddy (296 ± 81) and sandy soils (179 ± 13). We determined that distribution of generative diasporas of \textit{N. lutea} across large distances is related not only to presence of floating ability in the seeds, but also the "multi-step" process of their release: first – mericarps from fruits, and then seeds from mericarps. In the experimental conditions, most seeds directly sunk to the bed (70%) and the rest continued to float on the surface of the water during a month. Low germination of the seeds of the water-lily in the laboratory conditions (4–6%) with use of different means and terms of dry stratification was due to the fact that they have an organic morphophysiological intermediate type of rest. Having such a mechanism causes portioned and prolonged germination, allowing the species to survive in non-favourable conditions and accumulate generative diaspires in the soil. Despite the fact that the initial stages of ontogenesis in the laboratory and natural conditions have no significant differences, we found polyvariance in their tempo of development. First of all, this is related to different dates of transition of the plant from one age state to another. In the case of \textit{N. lutea}, one should also note the morphological polyvariance of ontogenesis related to change in morphologic characteristics of plants depending on the water level. The obtained results give a more complete picture of the peculiarities of generative reproduction of \textit{N. lutea}, necessary for understanding the ecosystem role of this plant and its impact on biological processes in water bodies.

Keywords: morphology of fruits; seed productivity; buoyancy of fruits; seed; germination; initial stages of ontogenesis.

Introduction

Reproduction is a multifaceted and multi-stage process which depends on different internal and external factors. Evaluation of the reproductive potential of species is based on a number of essential parameters, the main of which are the seed productivity and seed reproduction. These two processes are related to the number and morphological peculiarities of seeds, pattern of their distribution, ability to germinate and form seedlings. Solving these questions is relevant for aquatic and littoral plants distributed throughout the moderate zone of the Northern Hemisphere. Yellow water lily colonizes habitats which vary from the perspective of trophic level, speed of flow, chemical composition of water and soil (Smirnits et al., 1988; Padgett et al., 1999; Henriot et al., 2019). It easily inhabits new habitats where it can spontaneously disperse or be reintroduced (Kaplan et al., 1998). In rivers, the canopy of submerged leaves of \textit{N. lutea} is able to form an environment with a high content of nutrients (organic substances, total nitrogen and phosphorus) and low hydrodynamics, reminding one of conditions in flood plain lakes (Gunnell, 2014; Schoelynck et al., 2014). At the same time, growth and development of leaves of the water lily depend directly on the trophicity of the water body (Klok & van der Velde, 2017). It is especially important to note that natural-climatic conditions of the habitat have a significant impact on the processes of generative development of plants (Chernyak, 2018).

The materials on morphology and seed productivity of the fruits, their floating ability, and germination of the seeds of yellow water lily and the initial stages of ontogenesis which are available in the literature sources (Abizov & Tolkachev, 2016) are low-informative and fragmented (Heslop-Harrison, 1955; Dabyhna, 1982; Chernova, 2013, 2015). Insignificant brief data regarding only certain diagnostic features of fruits of yellow water lily (diameter of the stigma and number of rays in it) so-
times occur in a small number of guides and “Floras”. At the same time, it was noted that having a good rate of germination and vitality of the seedlings, *N. lutea* is ideal for laboratory experiments (Sütfeld et al., 1996).

Therefore, the objective of our study was determining the size characteristics and seed productivity of fruits of yellow water lily from different growing locations, as well as germination of the seeds after different pre-sowing processing and initial stages of ontogenesis of this species.

Materials and methods

Material for the study of size characteristics of fruits and seed productivity was collected in natural conditions of growth of yellow water lily in 2016 and 2019 in water bodies of Yaroslavl (the Riumnikovo Lake – 08.07.2016, the Rybinsk Reservoir – 04.08.2016) and Tver Oblasts (the Uglich Reservoir – 09.07.2019, the Sabro Lake – 08.08.2016 and Sig Lake – 09.08.2016, Fig. 1), and also lakes of the Republic of Belarus (Skripovo, Mlynok and Vydrennik – all, 26.07.2016). In each growing location, for measurement of morphological parameters of the fruit (length and diameter of fruit, length of the neck of the fruit, diameter and number of stigma rays) and determination of the number of seeds in them (Belyakov & Lapirov, 2019), 4–8 (12) fruits were collected.

The floating ability of fruits and mericarps of the studied species were studied in laboratory conditions. Fruits of *N. lutea* in amount of 10 (collected on 09.07.2019 in the Uglich Reservoir) were placed in glass vessels of 1.5 L capacity with standing tap water (the temperature of +20…+23 ºС). Over 30 days we monitored the process of cracking of the external coatings of the fruits, terms of release of mericarps and seeds from them.

Fig. 1. Cenoses of *N. lutea* in the locations where samples were collected: a – Riumnikovo Lake (Yaroslavl Oblast, Rostovsky District), b – the Korozhechna River, Mosalskoe village (Yaroslavl Oblast, Uglicksky District), c – bay of the Uglich Reservoir in the area of Harlovo village (Kashinsky District, Tver Oblast), d – Vydrenik Lake (Myadzel District, Minsk Oblast, Belarus)

Peculiarities of germination were studied on the seeds collected on 10.08.2018 in the highly overgrown lake extension of the Korozhechna River (Yaroslavl Oblast, Uglicksky district, near Masalskoe village). Some of the freshly-collected seeds were put into Petri dishes (30 seeds in each) on filter paper, then standing tap water (pH = 8.2) was added, and afterwards they were exposed to a luminostat (luminance of 3200 lx, 9/15 photoperiod (ligh/dark), the temperature ranging +19.3 ± 0.2 ºС (morning) to +30.0 ± 3.0 ºС (evening)). The remaining freshly-collected seeds were divided into three equal parts: one of them was kept in Petri dishes in the laboratory conditions, the second in the refrigerator (temperature of +2.5…+3.0 ºС), and the third in freezer (temperature of –24…–28 ºС). The dry cold stratification lasted for 4, 8 and 12 months.

The seeds were grown according to the general methods described in earlier works (Belyakov & Lapirov, 2015). We determined the following main parameters (Belyakov & Lapirov, 2015): lag-time (L) – time expressed in days between the beginning of the experiment and beginning of germination; final germination (Gfin or G) – percent of germinated seeds at the end of the experiment, corresponding to the term “laboratory germination” in the domestic literature (Nikolaeva et al., 1999); period of germination (P) – number of days during which the seeds germinate. The experiments were replicated three times, duration of experiments was 30 days.

The primary stages of ontogenesis of individuals of generative origin were surveyed in laboratory conditions. For this purpose, we used seedlings obtained from seeds collected in 2018 in Yaroslavl Oblast. The seedlings at the stages of opening of subulate leaf were planted from Petri dishes into desiccators 1/3 filled with sand (taken from natural growing locations), into water at the depth to 3–5 cm. Detailed morphological analysis of the above-ground and underground spheres of the plants (we recorded appearance of initial (embryonic) root, formation of a adventitious roots, development of the first and second and the following true leaves, the length of the rosette part of the shoot) was conducted once a day over the first week of the development, once a week over the first month of the development; once in two months (by 5–10 ones) over...
the second and the following months of the development. To measure the main morphological parameters of the seedlings, we used binocular microscopes MBS-10 and MSP-2 with micrometric scales. While describing the ontogenetic states and peculiarities of ontogenesis, we used the concept of discrete description and polyvariance of ontogenesis (Konarova et al., 2003; Savinykh & Chernyshinuka, 2015; Notov & Zhakov, 2019).

The obtained results are presented as mean value ± standard deviation (x ± SD). Data were analyzed in Statgraphics Centurion XVI (Stat-Point Technologies, Inc., USA, 2010). Significance of the differences between the values (P < 0.05) were determined using method of dispersion analysis (ANOVA) in PAST (Paleontological Statistics Software Package, Norway, 1999–2019, Hammer et al., 2001). For determining the significant differences, we used the Tukey test (with extension of Copenhaver & Holland, 1988 and Bonferroni correction).

**Results**

According to our data, in Central European Russia *N. lutea* blossoms from July to August, the fruits ripen in July–September. Fruit of the yellow water lily is oval or of egg-like conic form, with a truncated top, smooth, green. In the upper part it becomes the neck with the deeply lobed stigma disk surrounded by rays. The stigma disk is usually concave, round, rarely ellipsoid, with integral and slightly undulate margins. The size characteristics of the fruits which we collected in different water bodies are presented in Table 1.

### Table 1

| Water bodies, region | Lfr cm | Dfr cm | Lsr cm | Dsr cm | Nfr quantity |
|----------------------|--------|--------|--------|--------|--------------|
| Mlynok lake, Belarus (n = 5) | mean 3.4 ± 0.6 | range 1.8–4.0 | range 3.5 ± 0.4 | range 3.0–4.5 | range 3.0 ± 0.5 |
| Vydrennik lake, Belarus (n = 8) | mean 3.1 ± 0.3 | range 2.5–3.7 | range 3.2 ± 0.2 | range 3.0–3.5 | range 2.2–2.8 |
| Skripovo lake, Belarus (n = 8) | mean 3.1 ± 0.3 | range 2.5–3.7 | range 3.2 ± 0.2 | range 3.0–3.5 | range 2.2–2.8 |
| Sig lake, Tver Oblast (n = 8) | mean 3.0 ± 0.3 | range 2.5–3.4 | range 2.2–2.8 | range 2.2–2.8 | range 2.2–2.8 |
| Sabro lake, Tver Oblast (n = 4) | mean 2.2 ± 0.2 | range 1.8–2.7 | range 2.3–2.8 | range 2.3–2.8 | range 2.0–1.5 |
| Riumnikovo lake, Yaroslavl Oblast (n = 5) | mean 3.0 ± 0.3 | range 2.5–3.4 | range 2.2–2.8 | range 2.2–2.8 | range 1.8–2.7 |
| Rybinsk Reservoir, the Volga stretch, Yaroslavl Oblast (n = 4) | mean 2.2 ± 0.2 | range 1.8–2.7 | range 2.3–2.8 | range 2.3–2.8 | range 1.8–2.7 |

Note: Lfr – fruit length (cm), Dfr – fruit diameter (cm), Lsr – length of the fruit’s neck (cm), Dsr – diameter of the stigma of the fruit (cm), Nfr – number of rays of stigmas of fruit; differences are statistically significant at P < 0.05 (with Tukey test and Bonferroni correction) between the selections: Lfr – a–g, b–g, d–g, b–e; Dfr – c–e, c–g; Lsrfr – d–e, c–d, c–g; Nsr – a–c, b–c, c–d, c–e, c–f, c–g.

While analyzing the data given in Table 1, we should note that the inter-lake differences in some morphological parameters of the fruits were most notably manifested between the Belarus lakes and a number of lakes (Sig, Sabro and Riumnikovo) and the Volga stretch of Rybinsk Reservoir (RR), Sig lake and the Volga stretch of Rybinsk Reservoir (RR). Between all the rest of the selections, no morphological differences of the fruits were observed. At the same time, most morphological parameters of fruits from Sabro Lake and the Volga stretch of the Rybinsk Reservoir (Table 1) were reliably lower than the similar values of the lakes they were compared with.

Intrarelational differences in separate morphological parameters of the fruits were most notably manifested only in the Belarus lakes. Therefore, the reliable differences by number of rays of the stigma were observed between Mlynok and Skripovo lakes (P = 0.0240) and Vydrennik and Skripovo lakes (P = 0.0005). In Skripovo Lake, this parameter was significantly more notable than in the other two lakes (Table 1).

The data on seed productivity of the fruits of *N. lutea* in the central part of European Russia and the Republic of Belarus (x ± SD) are presented in Table 2.

### Table 2

| Water bodies | Seed productivity |
|--------------|-------------------|
| Mlynok lake  | mean 192.6 ± 40.5 |
| range 97–256 |
| Vydrennik lake | range 246.2 ± 81.2 |
| Sig lake | range 98–445 |
| Sabro lake | range 268.6 ± 52.8 |
| Riumnikovo lake | range 137–380 |
| Rybinsk Reservoir, the Volga stretch | range 204–307 |

Note: the number of analyzed fruits, parameters and the indications are the same as in Table 1.

In our experiments, conducted in the laboratory conditions, the release of the seeds from mericarps was observed during 2–3 hours. Then, most of the seeds of *N. lutea* (70%) and some with gradually decomposing mericarps sunk to the bottom of the laboratory cups, and the rest of seeds (30%) remained on the water surface until the end of the experiment (30 days). In the laboratory conditions, regardless of the terms of maintenance and character of stratification, the seeds germinated non-uniformly and singularly. Therefore, the final germination of the freshly-collected seeds of *N. lutea* which were kept 4 months in the freezer was very low...
(Table 3). Then, singular germinated seeds were observed only after dry cold stratification in the fridge (4 months). When kept for over 4 months (in different conditions) no seeds germinated.

**Table 3** Parameters of germination of seeds of *N. lutea* (x ± SD, n = 30)

| Parameter of germination | Freshly-collected | Period of stratification 4 months |
|--------------------------|-------------------|----------------------------------|
| L, days                  | 20.0 ± 2.0        | 3.3 ± 2.2                        |
| P, days                  | 3.0 ± 2.6         | 1.0 ± 0.0                        |
| Q<sub>0%</sub>           | 4.4 ± 1.4         | 2.2 ± 1.4                        |

*Note:* “–” – seeds did not germinate.

**Initial stages of ontogenesis of N. lutea** individuals of generative origin occurred in the following way.

**Latent period** Seeds of were almost smooth, glossy, ellipsoid or reverse egg-like shape, often slightly oblate at the sides, with a longitudinal outline turned towards the medial part of the testa, yellow-brownish, green-brownish, dark-brownish, or brownish in colour, up to 0.48 ± 0.10 cm in length and 0.26 ± 0.10 cm in diameter. At the basal part of seed, there is a truncated top with rounded cap of 0.9 ± 1.0 mm diameter. Embryo of *N. lutea* is straight, widely-conic in the apical part; has a well-developed bud, two cotyledons and hardly notable radicle.

**Seeding (p).** This age state, in laboratory conditions, lasted over 20 days. Germination of fruits of *N. lutea* occurs underground as follows: the cotyledons begin to lengthen, thus bursting the cap outside. With further lengthening of the cotyledons, the basal part of the embryo with embryonic root comes out through the hole in the seed. At the same time, the apical parts of the cotyledons remain submerged in the endosphere throughout the period of their existence, performing gastral function. The cotyledons which fused at the base, cover the terminal bud of the embryo. The hypocotyl (0.03 ± 0.01 cm in length) followed by embryonic root (0.05 ± 0.01 cm in length) is manifested poorly. The place where the hypocotyl transforms into embryonic root is characterized by serrated crown-like thickening.

On the 3–4th day, in the seedlings, a non-petiole sheathed leaf (3.62 ± 0.90 cm in length) develops, having subulate shape. The moment of its appearance is followed by active development of the epicotyl, which gradually increases in length. We observed death of subulate leaf in plants by the 45–49th days.

By the end of the 7–8th days, the first normal developed leaf emerged, having a petiole and leaf lamina. Its unfolding occurs usually at 9–10 days. This leaf was shifted by 180° in relation to the first (subulate) leaf. The leaf lamina in that leaf was narrow-lancet, or narrow-romb, with entire margins, light-green, thin, smooth, with clearly manifested central and several side veins. The unfolding of the first normal leaf implicates the emergence of the first inter-node adventitious root located within the first metamere of the developing rosette. We noted that usually the adventitious root was the longest, and the length of the subsequent adventitious roots varied on the unimodal curve. The length of the main root equals 0.83 ± 0.50 cm. In some cases the main root does not develop at all and dies.

By the end of the first – beginning of the second week of the seedling’s development, the epicotyl significantly increases in size, reaching 0.15 ± 0.06 cm in length and up to 0.1 cm in diameter. Growth of the hypocotyl, in this case, is significant, because particularly its bend causes change in the direction of growth of the main axis of the seedling in space – from orthotropically to anisotropically. At the same time, the hypocotyl continues to develop, increasing to 0.03 ± 0.01 cm in length and 0.08 cm in diameter.

Two weeks after the germination begins, unfolding of the second normal leaf takes place (1.43 ± 0.24 cm in length), the leaf lamina of which is widely-lancet or egg-like in shape. All the following leaves, which form on the area of the rhizome, are arranged spirally and partly overlap one another. During that period, the second adventitious root begins to form.

By the 20th day, in laboratory conditions, the cotyledon leaves die but remain connected to the plant for quite a long while. In the natural conditions this relation ruptures much earlier. The plant bears four leaves and two adventitious roots. The third normal leaf (3.16 ± 0.69 cm in length), similarly to all described earlier, is submerged, cordate arand row-shaped, with entire margins, light-green, semi-transparent, undulate at the margin. The capacity of the apical bud at this stage of the development of the plant reaches around 4.3 ± 0.4 primordial leaf. The main root reaches its maximum sizes (Table 6).

Therefore, by the end of this age state, the seedling is anisotropically growing rosette shoot (with three inter-nodes which grow in diameter in the basal area), bearing 4 assimilating leaves or 2 non-ramifying adventitious roots (Table 4).

**Table 4** Morphological parameters of the elements of the shoot sphere of seedling of *N. lutea*

| Organ of seedling | Morphologic parameters | Sizes, cm. |
|-------------------|------------------------|------------|
| Hypocotyl         | Length                 | 0.08 ± 0.03|
|                   | Diameter               | 0.12 ± 0.02|
|                   | Width                   | 0.13 ± 0.03|
| Epicotyl          | Diameter               | 0.12 ± 0.01|
|                   | Width                   | 0.13 ± 0.03|
|                   | Length                  | 2.07 ± 0.06|
|                   | Diameter               | 0.11 ± 0.03|
|                   | Width                   | 1.34 ± 0.17|
|                   | Length                  | 0.40 ± 0.04|
|                   | Diameter               | 2.22 ± 0.29|
|                   | Width                   | 1.55 ± 0.74|
| Basal area         | Length                 | 0.09 ± 0.03|
|                   | Diameter               | 0.11 ± 0.02|

**Juvenile plants (j).** Duration of age state fluctuates and depends on the time of formation of the first floating leaf.

The shoot continues to grow monopodially and orthotropically, being observed to have active development of the basal rosette region (Table 2). By the end of the first year of the development it is represented by 9 shortened internodes. The length of the basal area (not taking into account the epicotyl and hypocotyl) of the rosette shoot reaches 0.46 ± 0.02 and 0.26 ± 0.06 cm in diameter. At the same time, in the lower part of the rosette shoot, scars from 2–3 dead leaves are seen. At the same time, we observed complete death of hypocotyl and epicotyl. The capacity of the apical bud of the shoot comprised 4.5 ± 0.5 primordial leaf.

According to our observations, by the end of the first year of the development (fifth – beginning of the sixth month) the plants formed 11–12 leaves (around 2–3 of them died). We observed complete death of the second leaf by the days 115–129, the third leaf in most plants died by the days 140–150. The major mass of the leaves comprised submersed, cordate arrow-shaped, with entire margins, light green, semi-transparent leaves, and leaves with undulate margin. Nonetheless, sometimes in the apical part of the buds, heart-shaped, rougher leaves can be observed in the conditions of the experiment.

![Image](fig2.jpg)
be present, therefore the margins are straight, not undulate. All the parameters we measured in leaves (total length of leaf, length of the leaf sheath, length of the petiole, length and width of the leaf lamina) located towards the acropetal direction, gradually increased (to 6 leaves inclusively), and then the values of these parameters naturally reduced. At the same time, the sizes of the seventh and the subsequent leaf laminae usually did not exceed 1.32 ± 0.24 cm in length and 1.54 ± 0.20 cm in width. The auxiliary buds were absent. Furthermore, at the base of the apical bud and several opened leaves, hairs were present, represented by one row of thin-walled cells with transparent contents, which are interconnected.

In general, by the end of vegetation season, on the plant, 5–6 adventitious roots can form; usually 2 of them die. At the same time, the first adventitious root dies 1.5 months after the beginning of its development, while the second – after 2.0–2.5 months. The young roots are of white colour, old roots have orange-brownish tone. It should be noted that the first two adventitious roots do not ramify, and the ramification of the subsequent adventitious roots can reach n + 1 and n + 2 orders. Change in the linear sizes of the roots takes place along the unimodal curve. Maximum length of live roots at this stage of ontogenesis reaches 10.5 ± 2.0 cm (diameter at the base – 0.8 ± 0.1 mm).

Therefore, by the end of the first year of development, the juvenile plants are anisotropically growing rosette shoots, bearing 11–12 leaves and 5–6 adventitious roots which ramify to n + 1 order. We observed such plants in large amounts on the bottom of the Korozhechna River near Masalskoe village.

Discussion

The data on size characteristics of the fruits of yellow water lily are very poor. Thus, Dubyna (1982) has demonstrated that in aquatic objects of the former Ukrainian SSR, the jug-like, sometimes bottle-shaped fruit of this species is 4.5–7.0 cm in length and 3.0–5.0 cm in diameter, and the diameter of stigma disk reaches 1.43 ± 0.03 cm. At the same time, he distinguished N. lutea (var. luteum Coutinho,1892 and var. urceolatum Casp., 1857), having close values for length, diameter of the fruit and diameter of the stigma (Dubyna, 1982). These results, compared to our data (Table 1), demonstrate that significant differences were observed only for length of the fruit, which in Ukrainian plants was 1.5 times higher. This is confirmed by the materials by Chernova (2013) who compared aquatic, semi-aquatic and terrestrial forms of water yellow lily from Yaroslavl (the Il’ d River) and Voronezh Oblasts (the Bolshoe, Osnovskoe, Maloe Podpeschnoe and Sadilka lakes). She has shown that by the length of the fruit, significant differences between different ecological forms of Yaroslavl plants were absent. A different picture was observed for the other two parameters – diameter of fruit and stigma. Here, the reliable differences were observed between the parameters of aquatic and semi-aquatic, and also semi-aquatic and terrestrial forms. By contrast, different forms of the Voronezh plants were observed to have significant differences in length of the fruit, and also the diameter of fruit and stigma (between aquatic, semi-aquatic and terrestrial forms) (Chernova, 2013).

The differences indicated in the study for number of size characteristics of the fruits of yellow water lily in different aquatic objects are likely to be associated with differences in the growing locations by content of nutrients in water and soil. As indicated by the French researchers (Henriot et al., 2019), habitat rich in nutrients does not always positively affect the productivity of N. lutea negatively correlated with the concentration of nitrogen along all the depth of the bottom depositions (Henriot et al., 2019).

Comparing the seed productivity of the yellow water lily and other species of water lilies, we should note that according to our data this parameter for the rare species for the European Russia – N. pumila (Timm) DC. in the territory of Tver Oblast (the Kezrad lake) equaled 110.6 ± 24.5 seeds per fruit. Even lower is the seed productivity of this species in Japan, where it as rare as in our country and is represented by two forms: subspp. pumila (46.0 ± 39.0 seeds per fruit, Lippok & Renner, 1997) and subspp. urceolatum (Miki) Pedgrett (39.9 ± 203, variance range – 17–90) (Pedgrett et al., 2002).

Fruit of N. lutea is represented by spongy syncarpous berry-like multilocularis (Chernova, 2013). According to Dubyna et al. (1993), the duration of the period of ripening of the fruit reaches 35 ± 4 days, and the duration of the ripening of the fruits in the first half of the summer (compared to the second) reduces by 5–10 days. Often during the ripening, the fruit separates from the lower part of the pericarp, and then can drift for 2–3 days (Heslop-Harrison, 1955; Fer & Hroudova, 2008), being carried large distances by the water flows. This was also confirmed by our observations. Then, the fruits of N. lutea undergo cracking of the external cover – pericarp and release of mericarps which open hydrochazically (Abizov & Volkachkev, 2016). Similarly to the small part of the seeds released from mericarps, the mericarps of N. lutea themselves can for a short period remain floating. A similar picture was earlier described by American scientists (Hart & Cox, 1995) who noted dispersal of the seeds of yellow water lily on the surface of water (despite their negative buoyancy) in the glacial lakes of the Rocky Mountains in the West of the USA in two different ways: inside the floating fruits and inside floating but water-soluble matrix (probably indicating mericarps) which surrounds the seeds. The first way causes group dispersal of seeds, the second – scattered dispersal, when the fruits and seeds can move on the surface of water with the speed of up to 80 m/h (Hart & Cox, 1995).

We demonstrated that the seeds from N. lutea differ by duration and period of floating on the water surface. Such peculiarity was for the first time noted by Dutch scientists during studies on the buoyancy of the fruits of Sparganium emersum Rehm., which they named “bimodal dispersal strategy” (terminology of Pollut et al., 2009). In this case, this peculiarity can be associated with, first of all, large volume of the embryo itself, as well as presence of grains of starch in the endosperm of the testa, and aleuronic grains and additional fats, necessary for the development of the embryo, in the endosperm (Abizov & Tollakev, 2016). We should note that “bimodal dispersal ability” was observed earlier for hydrophytes, for example in three species Ranunculus L. (R. circinatus Sibth., R. kauffmannii Clerc and R. trichophyllus Chua) (Lebedeva & Laptev, 2013). Researchers (Lebedeva & Laptev, 2013) have shown that in the experimental conditions the major part of the achenes (~80%) from these plants can remain on the water surface for up to 90–110 days, while the rest sank to the bottom of the laboratory cups over 1–2 days.

Among the dominating “dispersing modes” (terminology of Sadlo et al., 2018), N. lutea prefers hydrochoria – distribution of fruits and seeds by water currents. In the lake ecosystems, there was also observed the process of anemohydrochoria – spread of fruits and seeds over the water surface by air flows. The literature data on the dispersal of the seeds of N. lutea vary. Therefore, Dubyna (1982) reports a distance of 8–10 km, the data of Abizov & Tollakev (2016) indicate the distribution of seeds across 5–20 and more km, Fer & Hroudova (2008) – 25 km. It seems that the distance of dispersal of the seeds is limited directly by the speed of the water flow (Dubyna, 1982). Based on their observations, Fer & Hroudova (2008) think that distribution of most seeds of Nuphar from the upper reach to the lower reaches occurs most often in the period of freshets rather than during the ripening of the seeds in the vegetation period. Earlier, Hart & Cox (1995) reported that though seeds of yellow water lily float only during 72 h, this time is enough for dispersal, especially in small glacial lakes connected by watercourses. Despite high parameters of the germination of seeds of N. lutea obtained by a number of authors (80–
April and continues until May, in summer it lasts from late July to late
depends on the illuminance and depth of water. This leaf locates at the
lops. Dubyna (1982) reports that the length of the leaf of such type directly
mentioned earlier, at the stage of seedling, the plant's first subulate leaf deve-
N. lutea
on of life of the subulate leaf coincide with the data of Turdiev (1960),
role of the subulate leaf at the initial stages of the development of a seedl-
tions of coleoptile in the cereals. Turdiev (1960) reported the significant
red pigment. We think that the functions of this leaf are similar to the func-
angle of 90° towards the cotyledon. Initially it is has no chlorophyll, but

Our surveys revealed that significant differences in a number of size
characteristics of the fruits of yellow water lily are most notably manifes-
ted between the Belarus lakes and a number of lakes (Sig, Sabro and Ruannikovo) and the Volga stretch of the Rybinsk Reservoir, and also the Sig lake and the Volga stretch of the Rybinsk Reservoir. At the same time, most morphological parameters of the fruits from Sabro Lake and the Volga stretch of the Rybinsk Reservoir (Table 1) were reliably lower than the similar values of the lakes which they were compared with. Intra-
regional differences in morphology of the fruits (number of rays of the
the stigma of the fruit) manifested most notably only in the Belarus lakes. All this confirms our opinion on the impact of ecological conditions of germi-
nation on the sizes of fruits, and also the formation of seeds and their
number. It seems that the seed productivity, as well as morphological peculiarities of fruits can depend on a number of internal and external
Factors. At the same time, their influence is not always positive.

Conclusions

Our surveys revealed that significant differences in a number of size
characteristics of the fruits of yellow water lily are most notably manifes-
ted between the Belarus lakes and a number of lakes (Sig, Sabro and Ruannikovo) and the Volga stretch of the Rybinsk Reservoir, and also the Sig lake and the Volga stretch of the Rybinsk Reservoir. At the same time, most morphological parameters of the fruits from Sabro Lake and the Volga stretch of the Rybinsk Reservoir (Table 1) were reliably lower than the similar values of the lakes which they were compared with. Intra-
regional differences in morphology of the fruits (number of rays of the
the stigma of the fruit) manifested most notably only in the Belarus lakes. All this confirms our opinion on the impact of ecological conditions of germi-
nation on the sizes of fruits, and also the formation of seeds and their
number. It seems that the seed productivity, as well as morphological peculiarities of fruits can depend on a number of internal and external
Factors. At the same time, their influence is not always positive.
The possibility of dispersal of seeds of *N. lutea* over long distances is due not only to the buoyancy of the seeds itself, but the “multi-step” process of their release – at first, the mericarps are released from the fruits, and then seeds from the mericarps. At the same time, the fruits, mericarps and seeds float for some time on the water surface. Such ability allows them to prolong the process of dissemination, and therefore allows the seeds to spread greater distances from the mother plant.

In our experiments the low germination ability of the seeds both freshly-collected and those after different terms of dry stratification is due to the condition of the endogenous (organic) morpho-physiological intermediate type of rest. The presence of this type of rest in natural conditions contributed to the formation of an ability of the plant in the natural populations which is very useful for adaptation, i.e. the mechanism of postponing germination, which enables seeds to grow in portions and over an extended period of time. At the same time, in the natural populations the vegetative reproduction of yellow water lily prevails over the generative, which is characteristic of most aquatic and shoreline plants.

The initial stages of ontogenesis of *N. lutea* are characterized by polyvariance in relation to the tempi of the development of the plant, which is expressed in different rates of the individual development (terms of transition of plant to the following age state) of generative diasporas in the natural conditions and aquarium conditions. In the case of *N. lutea*, obviously the morphological polyvariance of ontogenesis should manifest (as in the case of *Nymphaea odorata*), caused by the changes in morphological characteristics of the genet depending on the water level.

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