ISSN 2226-3063 e-ISSN 2227-9555
Modern Phytomorphology 13: 20–25, 2019

RESEARCH

Non-destructive estimation of the leaf area in *Nuphar lutea* L. (Nymphaeaceae)

Aleksandra M. Chernova*

Institute for Biology of Inland Waters RAS, Borok, Nekouzskiy District, Yaroslavl Region, 152742, Russia; *nuphar@mail.ru

Received: 11.11.2018 | **Accepted:** 07.02.2019 | **Published:** 14.02.2019

Abstract

Nuphar lutea (L.) Smith (Nymphaeaceae) is a widespread hydrophyte with leaves floating on the water. This highly productive plant forms a fairly large assimilating (photosynthesizing) surface. The purpose of this work was to develop a method for calculating the surface area of assimilating leaves of *N. lutea*. As a result, the formulas for calculating the surface area of a leaf (main photosynthetic organ of *N. lutea*) were obtained. The area formulas for the blade and petiole are based on the area formulas for geometrical figures and allow us to calculate the assimilating surface area of the yellow water-lily as precisely as possible. Therefore, the data obtained provide a better picture of this species productivity and will allow further to estimate the contribution of this species to the overall productivity of water bodies and watercourses

Keywords: Assimilating surface, photosynthesizing surface, hydrophytes, yellow water-lily

Introduction

Plant leaves are the main photosynthetic organ. The leaf shape depends on the plant species and correlates strongly with temperature and abiotic environment. The leaf area (LA) is the main parameter associated with the assimilating surface area, photosynthesis, respiration, transpiration, specific leaf area, and productivity (Filbin & Hough 1983; Klok & van der Velde 2017; Liu M.et al. 2017). The LA of a specified plant species indicates the performance of such mechanisms as radiation interception, water, and energy exchange. LA has been proven to be of great significance in plant growth studies and has helped with the understanding of plant-environment interactions (Gong et al. 2013; Costa et al. 2016). Exact and fast determination of this parameter is of great importance

There are several methods for determining LA. Direct measurements are based either on leaf harvesting and include grid count and gravimetric analysis or use of scanning area meter (e.g. LI-3000, Licor, NE, USA). Direct measurements of LA are considered to be the most accurate, but at the same time, they are destructive to plants, very time-consuming, and expensive (Jonckheere et al. 2004; Bréda 2008; Liu Z.et al. 2017). A portable scanning planimeter is only suitable for small plants with few leaves and not feasible for large leaves (Nyakwende et al. 1997; Rouphael et al. 2010). Moreover, these methods do not allow us to study the seasonal dynamics of leaf growth.

Indirect measurements are those methods based on observations and measurements of allometric parameters (leaf length and width) which are then used as input data for regression modeling (Blanco & Folegatti 2003; Jonckheere et al. 2004; Liu Z.et al. 2017). Such models are based on the correlation between allometric parameters of plants and their leaf areas (Bréda 2003; Jonckheere et al. 2004). These methods are non-destructive, fast and are suited for automation of all calculations (Costa et al. 2016). Mathematical modeling for dry land plants is widely applied by different investigators; thus, there are regression models for fast estimation of leaf area and weight of some broad-leaved species (Liu Z.et al. 2017). Regression models have been widely used to estimate the area and weight of leaves in a variety of crops such as maize (Birch et al. 1998), peach (Espinoza-Espinoza et al. 1998), coffee (Antunes et al. 2008), pepper (Rojas-Lara et al. 2008), avocado (Calderón et al. 2009), papaya (Cardona et al. 2009), mango (Ghoreishi et al. 2012), rose (Fascella et al. 2013), cocoa (Salazar et al. 2018) and olive (Koubouris et al. 2018). The equations obtained in each specific case approach only for a specific species.

Indirect methods also include photography and remote sensing with subsequent image interpretation. Nowadays, special software (Igathinathane et al. 2006) and mobile applications (Gong et al. 2013; Tech et al. 2018) are being developed for leaf area measurements.

Methods described above substantially belong to dry land plants. Unfortunately, there is a lack of published works for aquatic plants. There are only fragmentary data on LA of several hydrophytic species (Brock et al. 1983; Filbin & Hough 1983; Boese et al., 2008; Sinden-Hempstead & Killingbeck 1996).

At present, there is undoubtedly a need for obtaining LA data for aquatic plants. It is particularly important when studying the productivity of macrophytes in water bodies and watercourses and overgrowing of waters. This work is aimed to obtain the formulas for calculating the leaf area of hydrophytes with floating leaves. In this work, the yellow water-lily was used as a model species.

Nuphar lutea (L.) Smith (Nymphaeaceae Salisb.) is a species native to temperate regions of Europe and western Asia (Tcvelev 2000). Yellow water-lily is a hydrophyte with a thick (up to 15 cm) rootstock, floating and submerged leaves, triquetrous petiole, and large blades that are wide-elliptical to oval in shape. Flowers are yellow, up to 6.5 cm wide, on a cylindrical flower spike. Fruits are green, large, and have numerous seeds (up to 400 seeds per one fruit) which are olive-green and egg-shaped (Padgett 2007).

Associations with the yellow water-lily are typical for lakes, reservoirs, oxbows, and small and medium rivers. *N. lutea* forms both monodominant communities and communities with hydrophytes (*Lemna minor* L., *Ceratophyllum demersum* L., *Nymphaea alba* L., *Potamogeton lucens* L., *Potamogeton natans* L.) and helophytes (*Sagittaria sagittifolia* L., *Butomus umbellatus* L., *Sparganium erectum* L.). The aboveground form is an important part in the cenoses of hygrohelophytes and even mesophytes but it occurs only in dry shallow waters and less often on sandbanks. Due to its high ecological valency, *N. lutea* makes a considerable contribution to the total productivity of waterbodies and watercourses (Papchenkov 2001, Chernova 2015, Klok & van der Velde 2017).

N. lutea plays an important role in aquatic ecosystems-its high phytoncidal activity prevents water blooming, inhibits the development of pathogenic organisms (Dubyna 1982; Negrobov & Khmelev 1999) and fungi (Vergeer & van der Velde 1997), and has an allelopathic effect on other aquatic plants (Elakovich & Wooten 1991; Elakovich & Yang 1996; Macías et al. 2008). It is also an important food resource for animals (Heslop-Harrison 1955; Smits et al. 1989).

N. lutea is very important for the aquatic carbon cycle as it promotes the elimination of methane from benthal deposits (Dacey & Klug 1979). It accumulates heavy metals, such as Cu (Aulio 1980), Cd (Thompson et al. 1997), and some micronutrients (Klink 2004, 2005; Tomaszewicz 2009; Tomaszewicz & Ciecierska 2009). Studies of low-molecular-weight volatile organic compounds of aquatic macrophytes (including above-ground organs of *N. lutea*) are being conducted (Kurashov et al. 2014).

Materials and Methods

Plant material

The plant material for morphological studies and measurements of major parameters was collected during the growing season of 2010 (May to October) in the model rivers Ild (N 57°53'32,0″ E 038°03'41″) and Latka (N 58°04'24,8″ E 038°07'50″) which are tributaries of Rybinsk Reservoir (Fig. 1).

Cameral treatment of collected leaves included washing with tap water and separation leaf blades from petioles. In total, 1441 leaves were analyzed in terms of four parameters for leaf blades and in terms of three parameters for petioles.

Data analysis

For leaf blades, the blade length between the point of petiole attachment and the blade apex (l_1), total blade length (l_2), blade width (w), and height of the blade wing (h) (Fig. 2) were measured. To analyze morphometric parameters, correlation and regression analyses were used.

Results and Discussion

Based on the results of correlation analysis, the type of

Figure 1. Model rivers Ild (left) and Latka (right).

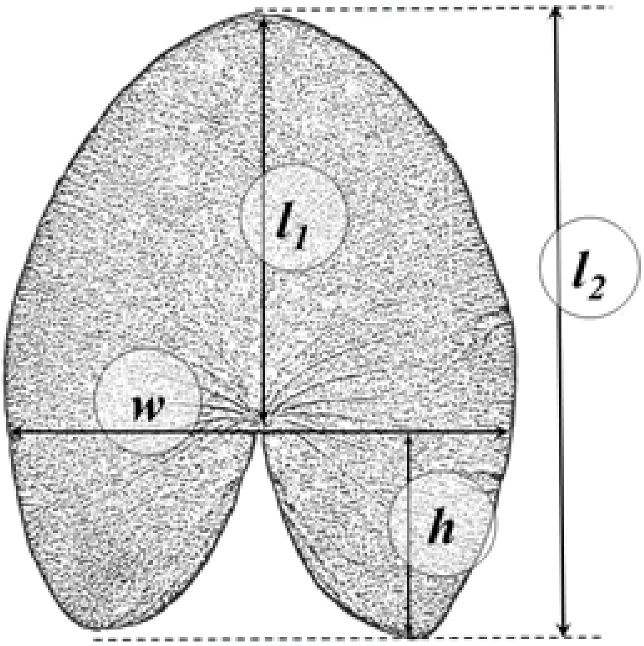

Figure 2. Major measurements parameters of leaf blade of *N. lutea*.

leaf blade growth (isometric or non-isometric), as well as dependencies between l_1 and l_2, between l_1 and w and between l_2 and w were determined. In the present research, a linear correlation coefficient (r) which shows the strength of the relationship and how changes of one parameter are due to the changes of another one was used (Tab. 1). Calculated paired correlation coefficient are considered significant at significance level α=0.05.

Such high correlation coefficients demonstrate a strong relationship between parameters of interest. On this basis, it was concluded that the growth is isometric and the leaf shape changes insignificantly in the growth process (Tab. 1).

Earlier it was determined that the height of the blade wing is slightly more than half of the blade length between the point of petiole attachment and the blade apex. The h/l_1 is constant and is equal to 3/5 (Chernova 2013).

The blades of *N. lutea* are oval to heart-shaped and conditionally consist of three parabolic segments *ABC*, *AEO* and *CDO* (last two-lateral wings-are fairly of the same area) (Fig. 3).

Therefore, the blade area (S_B) is a sum of the areas of three parabolic segments (1):

$$S_B = S_{ABC} + S_{AEO} + S_{CDO} = S_{ABC} + 2.S_{AEO} \quad (1)$$

The area of a parabolic segment is two-thirds multiplied by the product of the length of the line segment between the points of intersection and the distance from the horizontal line to the parabola vertex. Then the formula (1) will be as follows (2):

$$S_B = \frac{2}{3} \cdot AC \cdot BO + 2 \cdot \frac{2}{3} \cdot AO \cdot KE = \frac{2}{3} \cdot l_1 \cdot w + \frac{2}{3} \cdot h \cdot w \quad (2)$$

If express h in formula (2) in terms of l_1 (3):

$$S_B = \frac{2}{3} \cdot l_1 \cdot w + \frac{2}{3} \cdot \frac{3}{5} \cdot l_1 \cdot w = \frac{16}{15} \cdot l_1 \cdot w \approx l_1 \cdot w \quad (3)$$

Therefore, the blade area is approximately equivalent to the blade length (between the point of petiole attachment and the blade apex) multiplied by the blade width (measured through the point of petiole attachment to the blade). To determine the assimilating surface area, it is necessary to multiply the blade area by 2.

Table 1. Linear correlation coefficients (r) for parameters, l_1, l_2 and w.

Parameters	Ild river	Latka river
l_1 and l_2	0.97	0.96
l_1 and w	0.94	0.86
l_2 and w	0.94	0.86

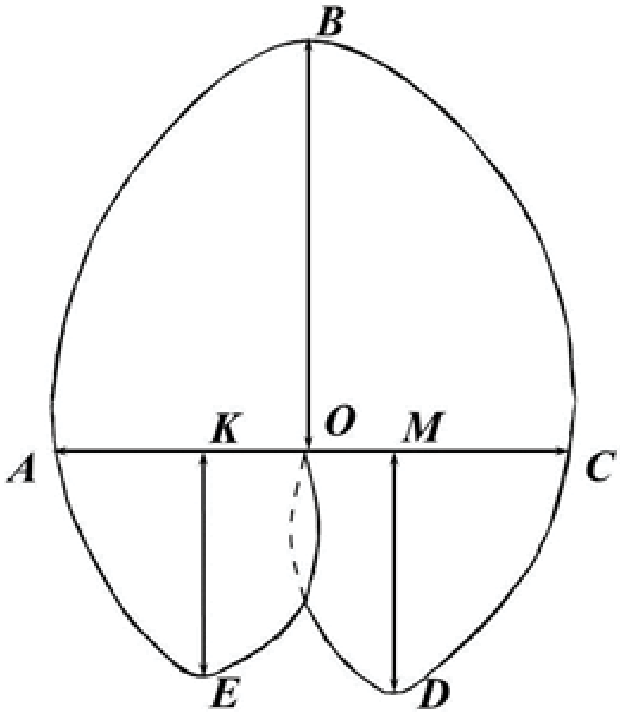

Figure 3. Schematic illustration of the leaf blade of *N. lutea*, conditionally divided into parabolic segments; *O*-point of petiole attachment to the blade, BO (l_1)-blade length between the point of petiole attachment and the blade apex; AC (w)-blade width measured through the point of petiole attachment to the blade, *KE* and *MD*- heights (h) of the blade wings.

The surface area of the petiole of *N. lutea* consists of three approximately equal geometric figures (trapezoids) (4)

$$S_p = 3 \cdot \frac{d_p + D_p}{2} \cdot p \quad (4)$$

where S_p - petiole surface area, d_p -average size of the petiole in the point of its attachment to the blade, D_p-average size of the petiole at the bottom, l_p-petiole length.

To obtain comparable data, the author of the present article proposes considering the petiole size in the point of its attachment to the blade and the petiole size at the bottom as constant values (for example, 0.7 cm and 1.7 cm). Then, to calculate the photosynthesizing surface area of the leaf, the petiole length only is needed.

As it was determined, the growth type of leaf blades of *N. lutea* is isometric (like of many other plants). In the growth process, *N. lutea* leaves change in size, but not in shape. Based on this fact, the formula for calculating such important parameter as LA was obtained. The proposed model is an indirect measurement of LA and has a measuring error.

When calculating the leaf area of *N. lutea*, it is necessary to realize that area formulas for geometrical figures are used. Therefore, there are some deviations from the actual values from the very beginning. However, this is a method error and this error is always the same. The formulas provided are suitable for calculating the photosynthesizing surface areas of corrugated submerged and floating leaves but not applicable in case of new rolled-up leaves. As a rule, the amount of such leaves is quite small (Chernova 2015) and their assimilating surface areas may be disregarded in case of field researches of large water bodies.

Previously, the regression method was applied to different fruit and vegetable crops (Montero et al. 2000; Buttaro et al. 2015; Blanco & Folegatti 2003; De Swart et al. 2004; Bakhshandeh et al. 2011; Silva et al. 2008; Zhang & Liu 2010; De Maria 2018; Tsialtas & Maslaris 2007; Firouzabadi et al. 2015) as well as to some woody plants (Cristofori et al. 2007; Koubouris et al. 2018). Authors of these studies carried out the regression analysis of leaf length, width, and area. The most of obtained regression equations are linear with general form y=ax+b. This is correct mathematically, but incorrect biologically-at zero leaf length and zero leaf width, leaf area is not equal to zero but is equal to b. probably, the authors would specify the leaf length and width ranges in which obtained formulas are correct. Nevertheless, the contribution to indirect measurements of LA made by these researchers is a basis for further studies.

The studies of LA of aquatic plants presented are some of the first. The formulas that were obtained can be applied in the field and are not destructive for phytocenoses allowing us to carry out seasonal studies of growth dynamics using the same plants and within the same sites. It is possible to determine the LA using two parameters only-the length and the width of the leaf blade.

The formulas obtained can be used to calculate the assimilating surface area of *N. lutea*. To do that it is necessary to know the number of leaves per unit area and the main morphometric parameters of leaves: the blade length measured between the point of petiole attachment and the blade apex, blade width measured through the point of petiole attachment to the blade, and petiole length.

If the number and size of leaves used for LA determination are large, the method can be time-consuming (Costa et al. 2016). However, such an approach is fast, reliable, and cost-effective.

Conclusion

The proposed indirect measurement of LA is a simple method that can be repeated by any researcher. This method allows us to obtain reliable LA values, identify the dynamics of plant growth and development. The only equipment required for this method is a simple ruler.

It may be considered, that the formulas obtained can be adapted to other Nymphaeaceae species as well as to other hydrophytes with floating leaves.

The author plans to continue studies to find formulas for indirect measurement of LA of other aquatic plants. Precise measurement of leaf area and leaf weight is necessary for a greater understanding of plant growth processes. In the future, the data obtained can form the basis for the modeling of aquatic ecosystems productivity.

Acknowledgment

For assistance in the preparation of the article, the author thanks D.A. Philippov (Institute for Biology of Inland Waters RAS).

The work was carried out within the government order of the Federal Agency for Scientific Organizations of the Russian Academy of Sciences for Papanin Institute for Biology of Inland Waters Russian Academy of Sciences (No. AAAA-A18-118012690099-2).

References

Filbin G.J., Hough R.A. 1983. Specific leaf area, photosynthesis, and respiration in two sympatric Nymphaeaceae populations. *Aquat. Bot.* **17:** 157-165. 10.1016/0304-3770(83)90111-0

Klok P.F., Van der Velde G. 2017. Plant traits and environment: floating leaf blade production and turnover of waterlilies. *PeerJ.* **5:** e3212. 10.7717/peerj.3212

Liu M., Wang Z., Li S., Lü X., Wang X., Han X. 2017. Changes in specific leaf area of dominant plants in temperate grasslands along a 2500-km transect in northern China. *Sci. Rep.* **7:** 10780. 10.1038/s41598-017-11133-z

Gong A., Wu X., Qiu Z., He Y. 2013. A handheld device for leaf area measurement. *Comput. Electron. Agric.* **98:** 74-80. 10.1016/j.compag.2013.07.013

Costa A.P., Pôças I., Cunha M. 2016. Estimating the leaf area of cut roses in different growth stages using image processing and allometrics. *Horticulturae.* **2: 6.** 10.3390/horticulturae2030006

Jonckheere I., Fleck S., Nackaerts K., Muys B., Coppin P., Weiss M., Baret F. 2004. Review of methods for in situ leaf area index determination. Part I. Theories, sensors, and hemispherical photography. *Agric. For. Meteorol.* **121:** 19-35. 10.1016/j.agrformet.2003.08.027

Bréda N.J.J. 2008. Leaf Area Index. *Encyclopedia of Ecology*. 457-462. 10.1016/b978-0-444-63768-0.00849-0

Liu Z., Zhu Y., Li F., Jin G. 2017. Non-destructively predicting leaf area, leaf mass and specific leaf area based on a linear mixed-effect model for broadleaf species. *Ecol. Indic.* **78:** 340-350. doi:10.1016/j.ecolind.2017.03.025

Nyakwende E., Paull C.J., Atherton J.G. 1997. Non-destructive determination of leaf area in tomato plants using image processing. *J. Hortic. Sci. Biotechnol.* **72:** 225-262. 10.1080/14620316.1997.11515512

Rouphael Y., Mouneimne A.H., Ismail A., Gyves E.M., Rivera C.M., Colla G. 2010. Modeling individual leaf area of rose (*Rosa hybrid* L.) based on leaf length and width measurement. *Photosynthetica.* **48:** 9-15. 10.1007/s11099-010-0003-x

Blanco F.F., Folegatti M.V. 2003. A new method for estimating the leaf area index of cucumber and tomato plants. *Hortic. Bras.* **21:** 666-669. 10.1590/s0102-05362003000400019

Bréda N.J.J. 2003. Ground-based measurements of leaf area index: a review of methods, instruments and current controversies. *J. of Exp. Bot.* **54:** 2403-2417. doi.org/10.1093/jxb/erg263

Birch C.J., Hammer G.L., Rickert K.G. 1998. Improved methods for predicting individual leaf area and leaf senescence in maize (*Zea mays*). *Aust. J. Agric. Res.***49:** 249-262. https://doi.org/10.1071/A97010

Espinoza-Espinoza J.R., Ortiz-Cereceres J., Mendoza-Castillo Ma. del C., Villaseñor-Alva J.A., Villegas-Monter A., Peña-Valdivia C., Almaguer-Vargas G. 1998. Regression models for the estimation of the fresh and dry weight of peach branches (*Prunus persica*, L. Batsh.). *Revista Chapingo Serie horticultura.* **4**: 125-131.

Antunes W.C., Pompelli M.F., Carretero D.M., Da Matta F.M. 2008. Allometric models for non-destructive leaf area estimation in coffee (*Coffea arabica* and *Coffea canephora*). *Ann. Appl. Biol.***153**: 33-40. 10.1111/j.1744-7348.2008.00235.x

Rojas-Lara P.C., Pérez-Grajales M., Colinas-León M.T.B., Sahagún-Castellanos J., Avitia-García E. 2008. Modelos matemáticos para estimar el crecimiento del fruto de chile manzano (Capsicum pubescens). *Rev. Chapingo Ser.Hortic.* **14:** 27-34.

Calderón A., Soto F., Calderón M., Fundora L.R. 2009. Estimation of foliar area in posts of mango (*Manguifera indica* l.) and aguacatero (*Persea spp*) in liver phase from the linear measures of the leaves. *Cultivos Tropicales.* **30:** 43-48. https://www.redalyc.org/pdf/1932/193217899007.pdf

Cardona A.C., Araméndiz H.T., Barrera C.C. 2009. Estimation of the leaf area of papaya (*Carica papaya* L.) based on non-destructive sampling. *Actualidad y Divulgación Científica.* **12:** 131-139. www.scielo.org.co/pdf/rudca/v12n1/v12n1a14.pdf

Ghoreishi M., Hossini Y., Maftoon M. 2012. Simple models for predicting leaf area of mango (*Mangifera indica* L.). *J. Biol. Earth Sci.* **2:** 845-853. newjournals.tmkarpinski.com/index.php/jbes/article/viewFile/15/20

Fascella G., Darwich S., Rouphael Y. 2013. Validation of a leaf area prediction model proposed for rose. *Chilean J. Agric. Res.* **73:** 73-76. 10.4067/S0718-58392013000100011

Salazar J.C.S., Melgarejo L.M., Bautista E.H.D., Di Rienzo J.A., Casanoves F. 2018. Non-destructive estimation of the leaf weight and leaf area in cacao (*Theobroma cacao* L.). *Sci. Hortic.* **229:** 19-24. 10.1016/j.scienta.2017.10.034

Koubouris G., Bouranis D., Vogiatzis E., Nejad A.R., Giday H., Tsaniklidis G., Ligoxigakis E.K., Blazakis K., Kalaitzis P., Fanourakis D. 2018. Leaf area estimation by considering leaf dimensions in olive tree. *Sci. Hortic.* **240:** 440-445. doi:10.1016/j.scienta.2018.06.034

Igathinathane C., Prakash V.S.S., Padma U., Babu G.R., Womac A.R. (2006). Interactive computer software development for leaf area measurement. *Comput. Electron. Agric.* **51:** 1-16. 10.1016/j.compag.2005.10.003

Tech A.R.B., Silva A.L.C., Meira L.A., Oliveira M.E. Pereira L.E.T. 2018. Methods of image acquisition and software development for leaf area measurements in pastures. *Comput. Electron. Agric.* **153:** 278-284. 10.1016/j.compag.2018.08.025

Brock T.C.M., Arts G.H.P., Goossen I.L.M., Rutenfrans A.H.M. 1983. Structure and annual biomass production of *Nymphoides peltata* (Gmel.) O. Kuntze (Menyanthaceae). *Aquat. Bot.* **17:** 167-188. 10.1016/0304-3770(83)90056-6

Boese B.L., Clinton P.J., Dennis D., Golden R.C., Kim B. 2008. Digital image analysis of *Zostera marina* leaf injury. *Aquat. Bot.* **88:** 87-90. doi.org/10.1016/j.aquabot.2007.08.016

Sinden-Hempstead M., Killingbeck K.T. 1996. Influences of water depth and substrate nitrogen on leaf surface area and maximum bed extension in *Nymphaea odorata*. *Aquat. Bot.* **53:** 151-162. 10.1016/0304-3770(96)01020-0

Tcvelev N.N. 2000. The determinant of vascular plants of North-West Russia (Leningrad, Pskov, Novgorod region). SPHFA, St. Petersburg. (In Russian).

Padgett D.J. 2007. A monograph of *Nuphar* (*Nymphaeaceae*). *Rhodora.* **109:** 1-95. doi.org/10.3119/0035-4902(2007)109[1:AMONN]2.0.CO;2

Papchenkov V.G. 2001. Vegetative cover of reservoirs and watercourses of the Middle Volga region. CMP MUBiNT, Yaroslavl. (In Russian).

Chernova A.M. 2015. Seasonal dynamics of yellow water lily *Nuphar lutea* (L.) Smith (*Nymphaeaceae*) in the small Ild river (Yaroslavl oblast). *Inland Water Biol.* **8:** 157-165. doi.org/10.1134/S1995082915020042

Dubyna D.V. 1982. Nymphaea of Ukraine. Naukova Dumka, Kiev. (In Russia)

Negrobov V.V., Khmelev K.F. 1999. Consortium analysis of the Salisb jugs family. Basin middle ground floor. Voronej. (In Russian).

Vergeer L.H.T., van der Velde G. 1997. Phenolic content of daylight-exposed and shaded floating leaves of water lilies (*Nymphaeaceae*) in relation to infection by fungi. *Oecologia.***112:** 481-484. 10.1007/s004420050335

Elakovich S.D., Wooten J.W. 1991. Allelopathic potential of *Nuphar lutea* (L.) Sibth. & Sm. (*Nymphaeaceae*). *J. Chem. Ecol.* **17:** 707-714. doi.org/10.1007/BF00994194

Elakovich S.D., Yang J. 1996. Structures and allelopathic effects of *Nuphar* alkaloids: nupharolutine and 6,6′-dihydroxythiobinupharidine. *J. Chem. Ecol.* **22:** 2209-2219. 10.1007/BF02029541

Macías F.A., Galindo J.L.D., García-Díaz M.D., Galindo J.C.G. 2008. Allelopathic agents from aquatic ecosystems: potential biopesticides models. *Phytochem. Rev.* **7:** 155-178. 10.1007/s11101-007-9065-1

Heslop-Harrison Y. 1955. *Nuphar* Sm. *The Journal of Ecology.* **43:** 342-364.

Smits A.J.M., Van Ruremonde R., Van der Velde G. 1989. Seed dispersal of three nymphaeid macrophytes. *Aquat. Bot.* **35:** 167-180. 10.1016/0304-3770(89)90103-4

Dacey J.W.H., Klug M.J. 1979. Methane efflux from lake sediments through water lilies. *Science.* **203:** 1253-1255. doi.org/10.1126/science.203.4386.1253

Aulio K. 1980. Accumulation of copper in fluvial sediments and yellow water lilies (*Nuphar lutea*) at varying distances from a metal processing plant. *Bull. Environ. Contam. Toxicol.* **25:** 713-717. https://doi.org/10.1007/BF01985597

Thompson E.S., Pick F.R., Bendell-Young L.I. 1997. The Accumulation of Cadmium by the Yellow Pond Lily, *Nuphar variegatum*, in Ontario Peatlands. *Arch. Environ. Contam. Toxicol.* **32:** 161-165. 10.1007/s002449900169

Klink A. 2004. The content of selected chemicals in two protected macrophytes: *Nymphaea alba* L. and *Nuphar lutea* (L.) Sibith & Sm. in relation to site chemistry. *Pol. J. Ecol.* **52:** 229-232.

Klink A. 2005. Chemical changes and nutrient release during decomposition processes of mature leaves of *Nuphar lutea* (L.) Sibith & Sm. under laboratory conditions. *Ecohydrol. Hydrobiol.* **5:** 215-222. 10.5586/asbp.2009.020

Tomaszewicz H. 2009. Changes in microelement content of rhizomes of *Nuphar lutea* (L.) Sibith & Sm. during the annual cycle. *Acta soc. Bot. Poloniae.* **78:** 257-262.

Tomaszewicz H., Ciecierska H. 2009. Changes in microelement content in *Nuphar lutea* (L.) Sibith & Sm. during the growing season. *Acta soc. Bot. Poloniae.* **78:** 151-165. 10.5586/asbp.2009.020

Kurashov E.A., Mitrukova G.G., Krylova J.V., Chernova A.M. 2014. Low-molecular-weight metabolites of aquatic macrophytes growing on the territory of Russia and their role in hydroecosystems. *Contemp. Probl. Ecol.* **7:** 433-448. 10.1134/S1995425514040064

Chernova A.M. 2013. Seasonal dynamics of the productivity of the yellow capsule (Nuphar lutea, Nymphaeaceae) in the conditions of small rivers of the Upper Volga region. Diss/PhD 03.02.08-ecology. Institute of Biology of Inland Waters named after I.D. Papanin. Borok. (In Russian)

Montero F.J., de Juan J.A., Cuesta A., Brasa A. 2000. Nondestructive methods to estimate leaf area in *Vitis vinifera* L. *Hort. Sci.* **35:** 696-698. journals.ashs.org/hortsci/view/journals/hortsci/35/4/article-p696.pdf

Buttaro D., Rouphael Y., Rivera C.M., Colla G., Gonnella M. 2015. Simple and accurate allometric model for leaf area estimation in *Vitis vinifera* L. genotypes. *Photosynthetica*. **53:** 1-8. doi.org/10.1007/s11099-015-0117-2

De Swart E.A.M., Groenwold R., Kanne H.J., Stam P., Marcelis L.F.M., Voorrips R.E. 2004. Non-destructive estimation of leaf area for different plant ages and accessions of *Capsicum annuum* L. *J. Hortic. Sci. Biotechnol.* **79:** 764-770. 10.1080/14620316.2004.11511 840

Bakhshandeh E., Kamkar B., Tsialtas J.T. 2011. Application of linear models for estimation of leaf area in soybean *Glycine max* (L.) Merr. *Photosynthetica.* **49**: 405-416. 10.1007/s11099-011-0048-5

Silva S.H., Lima J.D., Bendini H., Nomura E.S., Moraes W. 2008. Estimating leaf area in anthurium with regression functions. *Cienc. Rural.* **38:** 243-246. 10.1590/S0103-84782008000100040

Zhang L., Liu X.S. 2010. Non-destructive leaf-area estimation for Bergenia purpurascens across timberline ecotone, southeast Tibet. *Ann. Bot. Fenn.* **47:** 346-352. 10.5735/085.047.0504

De Maria S., Rita A., Trotta V., Rivelli A.R. 2018. Assessment of a non-destructive method to estimate the leaf area of *Armoracia rusticana*. *Acta Physiol. Plant.* **40:** 213-217. doi.org/10.1007/s11738-018-2789-2

Tsialtas J.T., Maslaris N. 2007. Leaf shape and its relationship with the leaf area index in sugar beet (*Beta vulgaris* L.) cultivar. *Photosynthetica.* **45:** 527-532. 10.1007/s1109 9-007-0090-5

Firouzabadi A.G., Raeini-Sarjaz M., Shahnazari A., Zareabyaneh H. 2015. Non-destructive estimation of sunflower leaf area and leaf area index under different water regime managements. *Arch. Agron. Soil. Sci.***61:** 1357-1367. 10.1080/03650 340.2014.1002776

Cristofori V., Rouphael Y., Mendoza-de Gyves E., Bignami C. 2007. A simple model for estimating the leaf area of hazelnut from linear measurements. *Sci. Hortic.* **113:** 221-225. 10.1016/j.scienta.2007.02.006