

REVIEW ARTICLE

Taxonomy of duckweeds (Lemnaceae), potential new crop plants

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ABSTRACT

Duckweeds are increasingly gaining interest because of their potential as a new aquaculture crop. In the present era of high throughput research, duckweed taxonomy has to be emphasized in order to support and strengthen scientific communication and commercial application. Since the publication of the fundamental monograph on Lemnaceae by E. Landolt in 1986, a number of changes have taken place in terms of their taxonomic position and nomenclature, which we summarize in this review. We report here about the systematic position of this plant family and the changes in its organization. Three additional species were identified; one new genus and subsequently one of the species was re-defined after the publication of the key of determination in 1986. At present Lemnaceae comprises of 37 species grouped into five genera. We envisage that this review will serve as a compilation of all these recent revisions, describing the state of art of duckweed systematics.

Keywords: Aquaculture; Duckweed; Lemnaceae; Taxonomy; Crop plant

INTRODUCTION

The present “blooming era” of “resurgence of duckweed research and applications” (Zhao et al., 2012; Lam et al., 2014; Appenroth et al., 2015b) is based mainly on their high potential for practical application. Lemnaceae comprises one of the fastest growing angiosperms (Sree et al., 2015c; Ziegler et al., 2015). In some Asian countries, duckweeds have been used for human nutrition for generations (Bhanthumnavin and McGarry, 1971; cf. van der Spiegel et al., 2013), because of their high protein content (Appenroth et al., 1982; Cheng and Stomp, 2009). Duckweeds have the potential to replace soya bean products at least partially as a source of protein. As demonstrated by several projects, duckweeds proved to be advantageous when fed to domesticated animals e.g., cattle, sheep, horses, rabbits (reviews in Landolt and Kandeler, 1987; Cheng and Stomp, 2009), poultry and water fowls (Muztar et al., 1979; Anderson et al., 2011), fish (Hassan and Edwards, 1992; Pipalova, 2003), and pigs (Van et al., 1997). Apart from their use as food and feed, duckweed biomass with high starch content produced under suitable cultivation conditions (Sree and

Appenroth, 2014; Sree et al., 2015a, b) can be used as a raw material for biofuel and biogas plants (Jain et al., 1992; Su et al., 2014; Cui and Cheng, 2015). This would substantially replace the use of food crops that are grown in arable lands as raw materials for biofuel production. Taken together, plants of this family have the potential as new crop plants.

Duckweeds, monocotyledonous aquatic plants, are represented by 37 species (Appenroth et al., 2013). This number is often cited incorrectly probably because of the following reason. In the year 2000, it became clear that *Lemna ecuadoriensis* is a synonym of *L. obscura* (Austin) Daubs (Landolt, 2000). But by mistake (personal correspondence to KJA), this merger was not considered in Les et al. (2002) and also not in Tippery et al. (2015). As a result, the total number of duckweed species was mentioned as 38 instead of 37, creating confusion to the readers. The 37 species are categorized into five well-defined genera (Fig. 1, Table 1): *Spirodela* (2 species), *Landoltia* (1), *Lemna* (13), *Wolffiella* (10) and *Wolffia* (11) (Appenroth et al., 2013). These aquatic angiosperms are cosmopolitan in distribution except for some endemic species (Landolt, 1986).

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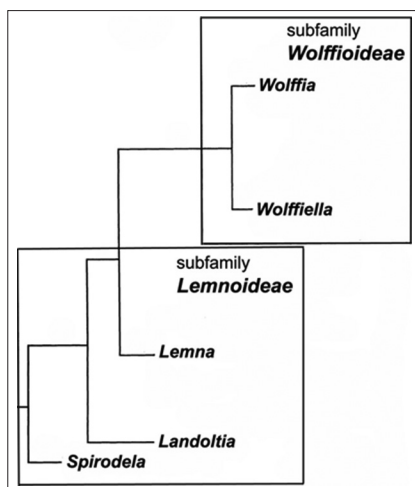


Fig 1. Internal structure of the family: Lemnaceae. The relation of genera and subfamilies based on Les et al. (2002) and Tippery et al. (2015).

Elias Landolt from ETH Zurich, Switzerland has collected duckweeds from all over the world since the mid-1950s and established a duckweed stock collection (Landolt, 1957; Appenroth et al., 2015a) which originally exceeded one thousand clones. Based mainly on morphological investigations, he published a “key of determination” of duckweeds (Landolt, 1980) which was later slightly modified in the first part of his famous monograph (Landolt, 1986). Within the last three decades, quite a number of changes have been introduced to taxonomic classification of duckweeds in comparison to the published key. Moreover, molecular taxonomy and barcoding of duckweed species (Wang et al., 2010; Bog et al., 2010, 2013, 2015; Borisjuk et al., 2015) has made huge progress and it aids in identification of duckweed species. However, it is not practically and economically viable to determine each of the collected duckweed clones by Amplified Fragment Length Polymorphism (AFLP) or by sequencing of DNA markers. Therefore, determination of duckweed species based on their morphology remains crucial for their identification. An update to the “key of determination” of all the duckweed species known to date is a prerequisite to facilitate accuracy in communication amongst researchers in academia and industry, and also entrepreneurs in this field, especially keeping in view the practical applications of duckweeds.

In this review we discuss the taxonomic position of duckweeds and the classification changes made since the publication of Landolt’s monograph in 1986 (Table 2). This revision shall help students and newcomers to the field of duckweed research and applications to become quickly acquainted with this expanding field and to use the accurate terms and nomenclature.

Table 1: Presently accepted genera and species of the plant family Lemnaceae Dumort

Subfamily	Genera	Species		
Lemnoideae Engl.	<i>Spirodela</i> Schleid.	<i>S. polyrrhiza</i> (L.) Schleid.		
		<i>S. intermedia</i> W.Koch		
	<i>Landoltia</i> Les & Crawford	<i>L. punctata</i> (G.Mey.) Les & D.J.Crawford		
		<i>Lemna</i> L.		
		<i>L. disperma</i> Hegelm.		
		<i>L. gibba</i> L.		
		<i>L. japonica</i> Landolt		
		<i>L. minor</i> L.		
		<i>L. obscura</i> (Austin) Daubs		
		<i>L. turionifera</i> Landolt		
		<i>L. trisulca</i> L.		
		<i>L. aequinoctialis</i> Welw.		
		<i>L. perpusilla</i> Torr.		
		<i>L. tenera</i> Kurz		
		<i>L. minuta</i> Kunth		
		<i>L. valdiviana</i> Phil.		
		<i>L. yungensis</i> Landolt		
		Wolffioideae Engl.	<i>Wolffiella</i> Hegelm.	<i>W. caudata</i> Landolt
				<i>W. denticulata</i> (Hegelm.) Hegelm.
<i>W. gladiata</i> (Hegelm.) Hegelm.				
<i>W. lingulata</i> (Hegelm.) Hegelm.				
<i>W. neotropica</i> Landolt				
<i>W. oblonga</i> (Phil.) Hegelm.				
<i>W. welwitschii</i> (Hegelm.) Monod				
<i>W. rotunda</i> Landolt				
<i>W. hyalina</i> (Delile) Monod				
<i>W. repanda</i> (Hegelm.) Monod				
<i>Wolffia</i> Horkel ex Schleid.	<i>W. angusta</i> Landolt			
	<i>W. arrhiza</i> (L.) Horkel ex Wimm.			
	<i>W. columbiana</i> H.Karst.			
	<i>W. cylindracea</i> Hegelm.			
	<i>W. elongata</i> Landolt			
	<i>W. globosa</i> (Roxb.) Hartog & Plas			
	<i>W. neglecta</i> Landolt			
	<i>W. australiana</i> (Benth.) Hartog & Plas			
	<i>W. borealis</i> (Engelm. ex Hegelm.) Landolt			
	<i>W. brasiliensis</i> Wedd.			
	<i>W. microscopica</i> (Griff.) Kurz			

Taxonomic position of the family Lemnaceae

Duckweed species are monophyletic with those of the Araceae (Cabrera et al., 2008; Cusimano et al., 2011). However, the branching appears to have started about 104 Ma ago in the Early Cretaceous when the breakup of Pangea was in its final stage (Nauheimer et al., 2012). This is one reason why we prefer keeping Lemnaceae as a family of its own (Appenroth et al., 2015a). The monophyly does not necessarily mean that duckweeds have to be integrated into the family of Araceae and be treated as a subfamily Lemnoideae, as preferred e.g. by Nauheimer et al. (2012).

Table 2: Newly discovered species and revised nomenclature after the publication of the duckweed monograph by Landolt (1986)

S. No.	Presently accepted nomenclature	Old nomenclature (not valid=synonym)	Reference
1	<i>Landoltia punctata</i> (G.Mey.) Les & D.J.Crawford	<i>Spirodela punctata</i> <i>Spirodela oligorrhiza</i> <i>Spirodela sichuanensis</i>	Les and Crawford (1999) Li and Landolt (2010)
2	<i>Spirodela polyrhiza</i> (L.) Schleid.	<i>Spirodela polyrrhiza</i>	Appenroth et al. (1990)
3	<i>Lemna aequinoctialis</i> Welw.	<i>Lemna paucicostata</i> <i>Lemna aoukikusa</i>	Landolt (1986) Borisjuk et al. (2015)
4	<i>Lemna minuta</i> Kunth	<i>Lemna minuscula</i>	Reveal (1990)
5	<i>Lemna obscura</i> (Austin) Daubs	<i>Lemna ecuadoriensis</i>	Landolt (2000)
6	<i>Lemna valdiviana</i> Phil.	<i>Lemna valdesiana</i>	Landolt (1986)
7	<i>Wolffiella caudata</i> Landolt	New species	Landolt (1992)
8	<i>Wolffia neglecta</i> Landolt	New species	Landolt (1994)
9	<i>Wolffia cylindracea</i> Hegelm.	Newly defined	Landolt (1994)

One can separate the small group of Protoaraceae together with Lemnaceae from the “true Araceae” (as these two groups are the most basal elements in this group), which results in three monophyletic plant families, i.e. true Araceae, Lemnaceae and Protoaraceae (Appenroth et al., 2015a). The following additional arguments speak in favour of designating Lemnaceae as a family on its own (Appenroth et al., 2013): (1) The notion to unify Araceae and Lemnaceae originated from a certain similarity between *Pistia* spp. and some duckweeds, especially *Spirodela polyrhiza* L. (Schleid.) (Hooker and Brown, in Smith, 1824). On the basis of more recent morphological and molecular investigations (Cusimano et al., 2011), it is now clear that this similarity is only superficial. (2) The characteristics of the members of Lemnaceae which are similar to those of Araceae at the morphological, anatomical or biochemical levels are not only restricted to Araceae but are similar in all Alismatales. (3) All species belonging to Lemnaceae together form a well-defined unit on morphological, biochemical and habitat bases.

The current systematic investigations into the evolutionary and taxonomic relationships between the five genera of Lemnaceae are represented in Fig. 1 (cf. Les et al., 2002; Tippery et al., 2015) and the classification of these five genera into 37 species has been depicted in Table 1.

Newly discovered species

The following three species were discovered after 1986:

Wolffiella caudata Landolt

Wolffiella caudata was first described by E. Landolt in 1992. It was found to grow in the southwestern part of the Amazon basin within the inundation area of the tributary rivers, e.g. Yacuma and Tahuamanu, in Bolivia. More information on its identification can be found in Landolt (1992). A chemotaxonomic study of the genus *Wolffiella* including *W. caudata* was performed by Crawford et al. (1997) based on the allozyme profiles. Barcoding (Wang et al., 2010; Borisjuk et al., 2015) and a detailed molecular

taxonomic investigation of this species based on AFLP and plastidic marker sequences (unpublished data; Bog, Sree and Appenroth) has been carried out recently together with other species of the genus *Wolffiella*. These investigations further support its species identity.

Wolffia cylindracea Hegelm.

Wolffia cylindracea was found in seasonal waters of winter-dry subtropical to tropical regions of Africa, south of the equator, e.g. Angola (Landolt, 1994). Although this species was first described by C.F. Hegelmaier as early as 1868 (Hegelmaier, 1868), researchers of the later century did not consider it and incorporated it into the species *W. globosa* (Roxb.) Hartog & Plas (Daubs, 1965; Landolt, 1986). The distinctness of the African clones of *W. globosa* in the chemotaxonomic investigations led to the rediscovery of this group of African plants as a separate species, *W. cylindracea*, as already suggested by Hegelmaier (Landolt, 1994; Crawford and Landolt, 1995). The molecular taxonomic studies on this species also clearly distinguish this species from its relatives (Bog et al., 2013; Borisjuk et al., 2015).

Wolffia neglecta Landolt

Wolffia neglecta (Landolt, 1994) was found in the winter-dry subtropical to tropical regions of India (e.g. Rajasthan), Pakistan, and Sri Lanka and probably exists in seasonal waters. The classification of these plants as new species was supported by chemotaxonomic methods (Crawford and Landolt, 1995).

Detailed morphological description of *W. cylindracea* and *W. neglecta* annexed with photographs and very useful drawings are presented in Landolt (1994).

Changes in the species nomenclature

It is worth mentioning that in plant systematics the term “synonym” has an unusual meaning. It describes the same species (which would be in agreement with the common usage of the term) but also means that this name is no

longer valid and should not be used. We would like to cite from a letter of W. S. Hillman published by E. Landolt (1986, p. 444): “When the late Dr. Wm.S. HILLMAN (Brookhaven, NY) learned that the name *L. paucicostata* had to be changed again, he wrote to me in an understandable reaction: “I am filled with horror or laughter (I am not sure which) at the thought of again changing the name under which we write articles about poor old 6746 and its brethren. And the names get worse and worse for the ordinary (English-speaking anyway) person to handle: *perpusilla* -” *paucicostata* -” *aequinotialis*. And please, I do beg of you, conceal the reference from me as long as possible, since people who read the physiological literature tend to be intolerant of such things”.” Although this reaction is understandable, results of the investigations in the field of plant systematics should be respected by other plant scientists.

The most dramatic change in duckweed terminology took place when the molecular taxonomic investigations of Les and Crawford (1999) resulted in the decision to create a new genus, *Landoltia* Les & D.J.Crawford. As a consequence, *Spirodela punctata* (formerly termed as *Spirodela oligorrhiza*) was renamed as *Landoltia punctata* (G.Mey.) Les & D.J.Crawford, and *S. oligorrhiza* and *S. punctata* became synonyms of *L. punctata*. This change in nomenclature was challenged by Ward (2011). Because the type specimen described as *Lemna punctata* by G. F. W. Meyer was lost, he suggested a neotypification but with *Spirodela intermedia* as a type. As already stressed by E. Landolt (cited in Wiersema, 2015) this would lead to considerable confusion in duckweed nomenclature (cf. for the genus *Spirodela* in Plant List, Version 1.1, 2013, <http://www.theplantlist.org>). More recently, Wiersema (2015) made it clear that the valid name of this species is *Landoltia punctata*. However, such a drastic change in botanical nomenclature has the unfortunate consequence that the old but crucial and basic research (e.g. Mattoo et al., 1984; Greenberg et al., 1987) published under the old name of the species (e.g. *Spirodela oligorrhiza*) cannot be retrieved by the internet search machines using the new nomenclature (e.g., *Landoltia punctata*).

Another interesting change is the spelling of the species name, *Spirodela polyrrhiza*. Landolt (1986) considered this spelling of the species to be an orthographic mistake of the term *polyrrhiza* with two ‘r’s and used the spelling *Spirodela polyrrhiza*. But as pointed out by Appenroth et al. (1990), *Spirodela polyrrhiza* with one ‘r’ is the valid name as written by its author von Linné (Linnaeus, 1753).

Two of the *Lemna* species should be mentioned in this context. The first one is *Lemna aequinoctialis* Welw. Its synonym, *Lemna paucicostata*, which was replaced many years ago is still being used and the species name is

wrongly cited (e.g. Murata et al., 2014). *Lemna aoukikusa* (as mentioned in Yamaga et al., 2010) is also a synonym of *Lemna aequinoctialis* (Landolt, 1986). This decision was recently confirmed by Borisjuk et al. (2015) based on the plastidic sequence analysis. In a second case, Reveal (1990) found out that there was already an older and valid name for *Lemna minuscula*. As a consequence and following the rules of plant systematics, the name of the species *Lemna minuscula* had to be changed to *Lemna minuta* Kunth and the term *L. minuscula* became a synonym. It is worth to mention that the species of the genus *Lemna* are characterized by the presence of one root (Landolt, 1980). The names *Lemna polyrrhiza* and *Lemna arrhiza* are therefore not valid (Landolt, 1986). The valid names are *Spirodela polyrrhiza* and *Wolffia arrhiza* Horkel ex Wimm. (Iamonico and Iberite, 2014). Iamonico and Iberite (2014) also lectotypified the two Linnaean names: *Lemna polyrrhiza* and *Lemna arrhiza*. Although invalid, the first one is still being used (e.g. *Lemna polyrrhiza* in Bairagi et al., 2002; *Lemna polyrrhiza* in John et al., 2008). Apart from the fact that these names are invalid, they are in evident conflict with the meaning of the terms “polyrhiza” (= many roots) or “arrhiza” (= rootless) under the genus *Lemna*.

As a supplementary material we have compiled all the synonyms of the 37 duckweed species, which we became aware over the years. The valid names are given in each case. The Plant List (Version 1.1, 2013, <http://www.theplantlist.org>), a working list of all known plant species, mentions two additional accepted duckweed species names: *Spirodela sichuanensis* M.G.Liu & K.M.Xie and *Lemna valdesiana* S.Watson. However, both species were reviewed by Landolt and were treated as synonyms for *Landoltia punctata* (Li and Landolt, 2010) and *Lemna valdiviana* (Landolt, 1986), respectively.

Registration of clones

To facilitate comparison of the research results within different duckweed labs, it has been suggested to register the clones of the duckweed species and obtain a four-digit code introduced by Elias Landolt (ISCDRA Newsletter No. 1; http://lemnepedia.org/wiki/International_registration_of_duckweed_clones). This code can be cited in scientific communications for easy reference. Registration can be done at the home page of the Rutgers Duckweed Stock Cooperative (Head: Prof. Dr. Eric Lam, Rutgers, State University of New Jersey, New Brunswick, USA: <http://www.ruduckweed.org/>).

CONCLUSIONS

Use of accurate scientific nomenclature of the duckweed species needs to be stressed in view of the considerable

number of changes in duckweed systematics in the recent past. Efforts should be made to disseminate this up-to-date information to duckweed researchers as well as to the general readers. In general interest and convenience of both the authors and the readers, it is recommended that the synonym (invalid old name of a species) of a duckweed species be mentioned in braces at the first mention of the new name of the duckweed species in a text. With the current advancements in the field of molecular biology, barcoding and molecular taxonomy of Lemnaceae members have already reached a considerable level. Nevertheless, morphological identification of duckweeds still remains significantly important and cannot be superseded. For instance, *Wolffia neglecta*, a species described by E. Landolt on a morphological basis, can hardly be separated out as a species on its own using the methods of molecular taxonomy (Bog et al., 2013). On the other hand, molecular taxonomy aids in investigating some of the minute details. The term *Lemna jungensis* Landolt must be specially mentioned. This species was introduced mainly by eco-geographic reasons because it was discovered on wet rocks that are in permanent contact with flowing waters (Landolt, 1998). However, according to our investigations, the morphological differences between *L. jungensis* and *L. valdiviana* Phil. are not very distinct and the molecular analysis also does not provide markers for a clear differentiation between the two species (Bog et al., 2010; Borisjuk et al., 2015). In-depth molecular analysis might provide a substantial basis for further conclusions in this respect.

Author's contributions

All three authors discussed together the idea to support the "International Steering Committee on Duckweed Research and Applications" in creating scientific standards for duckweed research. Also all three authors contributed by evaluating relevant literature. KJA made a first draft which was modified by KSS and MB.

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SUPPLEMENTARY MATERIAL

Synonyms of Lemnaceae species

***Landoltia punctata* (G.Mey.) Les & D.J.Crawford (Novon 9: 532, 1999)**

- Lemna punctata* G.Mey. (Prim. Fl. Esseq. 262, 1818);
Lemna gibba Blanco (Fl. Filip. 672, 1837);
Lemna oligorrhiza Kurz (J. Linn. Soc. Bot. 9: 267, 1866);
Lemna melanorrhiza F. Muell. ex Kurz (J. Bot. 5: 115, 1867);
Lemna pleiorrhiza F. Muell. ex Kurz (J. Bot. 5: 115, 1867);
Spirodela oligorrhiza (Kurz) Hegelm. (Lemnac. 147, 1868);
Lemna pusilla Hegelm. (Lemnac. 147, 1868);
Lemna javanica F.A.Bauer ex Hegelm. (Lemnac. 150, 1868);
Spirodela oligorrhiza var. *melanorrhiza* (F. Muell. ex Kurz) Hegelm. (Lemnac. 148, 1868);
Spirodela oligorrhiza var. *pleiorrhiza* (F. Muell. ex Kurz) Hegelm. (Lemnac. 149, 1868);
Spirodela oligorrhiza var. *pusilla* Hegelm. (Lemnac. 149, 1868);
Spirodela oligorrhiza var. *javanica* Hegelm. (Lemnac. 150, 1868);
Spirodela melanorrhiza (F. Muell. ex Kurz) Hegelm. (Bot. Jahrb. Syst. 21: 287, 1895);
Spirodela pusilla (Hegelm.) Hegelm. (Bot. Jahrb. Syst. 21: 287, 1895);
Spirodela javanica (Hegelm.) Hegelm. (Bot. Jahrb. Syst. 21: 288, 1895);
Spirodela pleiorrhiza (F. Muell. ex Kurz) Hegelm. (Bot. Jahrb. Syst. 21: 288, 1895);
Spirodela punctata (G.Mey.) C.H. Thomps. (Rep. (Annual) Missouri Bot. Gard. 9: 28, 1898);
Spirodela sichuanensis M.G.Liu & K.M.Xie (J. Southwest. Agric. Coll. (Chongqing) 4: 56, 1983);
Spirodela seemanii Hegelm. in herb. (STU - Stuttgart, Germany)*

***Lemna aequinoctialis* Welw. (Apont. 578, 1859)**

- Lemna obcordata* Bojer (Hortus Maurit. 358, 1837);
Lemna minor Griff. (Not. Pl. Asiat. 3: 216, 1851) et auct. mult;
Lemna anqolensis Welw. (J. Bot. 3: 112, 1865);
Lemna perpusilla var. *trinervis* Austin (Manual ed. 5: 479, 1867);
Lemna paucicostata Hegelm. (Lemnac. 138, 1868);
Lemna paucicostata var. *membranacea* Hegelm. (Lemnac. 141, 1868);
Lemna trinervis (Austin) Small (Fl. S.E. U.S. 230, 1903) et auct.;
Lemna minima Blatt. & Hallb. (J. Indian Bot. 2: 50, 1921);
Lemna blatteri McCann (J. Bombay Nat. Hist. Soc. 42: 153, 1942);
Lemna eleanorae McCann (J. Bombay Nat. Hist. Soc. 42: 154, 1942);
Lemna aoukikusa T.Beppu & Murata (Acta Phytotax. Geobot. 36: 55, 1985);
Lemna aoukikusa subsp. *bokurikuensis* T.B eppu & Murata (Acta Phytotax. Geobot. 36: 56, 1985);
Lemna paucicostata var. *subsymetrica* Hegelm. in herb. (STU - Stuttgart, Germany)*;
Lemna monandra Wight in herb. (LE - Saint Petersburg, Russia)*;
Lemna obliqua Sutter in herb. (MO - Saint Louis, Missouri, USA)*;
Lemna perpusilla auct.*;
Lemna perpusilla var. *paucicostata* Hegelm.*

***Lemna disperma* Hegelm. (Bot. Z. 29: 654, 1871)**

- Lemna disperma* var. *fallax* Hegelm. (Bot. Jahrb. Syst. 21: 291, 1895);
Lemna minor var. *gunnii* Hegelm. (Bot. Jahrb. Syst. 21: 292, 1895);
Lemna biovulata Hegelm. in herb. (STU - Stuttgart, Germany)*

***Lemna gibba* L. (Sp. Pl. 970, 1753)**

- Lemna vulgaris* Lam. (Fl. Franç. (Lamarck) 2: 189, 1779) [1778 publ. after 21 Mar 1779];
Lenticula gibba Lam. (Fl. Franç. (Lamarck) 2: 189, 1779) [1778 publ. after 21 Mar 1779];

Lenticula gibba (L.) Moench (Methodus 319, **1794**);
Lenticula gibbosa P. Renault (Fl. Orne 40, **1803**);
Thelmatophace gibba (L.) Schleiden (Linnaea 13: 391, **1839**);
Lemna trichorrhiza Thuill. ex Schleid. (Linnaea 13: 391, **1839**);
Thelmatophace gibbosa (P. Renault) Montandon (Guide Bot. 308, **1868**);
Lemna cordata Sessé & Moc. (Pl. Nov. Hisp. 159, **1890**);
Thelmatophace generalis E.H.L. Krause (Deutschl. Fl. ed. 2, 1: 184, **1906**);
Lemna parodiana Giardelli (Notas Mus. La Plata, Bot. 2: 97, **1937**);
Lemna tertiaria (fossil near *L. gibba*) Dorofeev (Akad. Nauk SSSR 129-130, **1963**);
Lemna symmeter G. Giuga (**1973**)*

***Lemna japonica* Landolt (Veröff. Geobot. Inst. ETH Stiftung Rübel Zürich 70: 23, 1980)**

Lemna leiboensis M.G. Liu & C.H.Hou (J. Southwest. Agric. Coll. (Chongqing) 4: 58, **1983**)

***Lemna minor* L. (Sp. Pl. 970, 1753)**

Lenticula aquatica Brunfels (**1530**)*;
Lenticula palustris H. Bock (**1539**)*;
Lenticula vulgaris Hill (**1757**)*;
Lenticula palustris Garsault (Fig. Pl. Méd. t. 336, **1764**);
Lenticula minor (L.) Scop. (Fl. Carniol. ed. 2: 213, **1772**);
Hydrophace monorrhiza Haller ex Scop. (Fl. Carniol. ed 2: 213, **1772**);
Lenticula vulgaris Lam. (Fl. Franç. 2: 189, **1779**);
Lemna vulgaris (Lam.) Lam. (Encycl. 3: 464, **1792**);
Lemna minima Thuill. ex P.Beauv. (J. Phys. Chim. Hist. Nat. Élément 82: 113, **1816**);
Lemna palustris Haenke ex Mert. & W.D.J.Koch (Deutschl. Fl. ed. 3 (1):295, **1823**);
Lemna minor var. *minima* Chev. (Fl. Gén. Env. Paris 2: 256, **1827**);
Lemna cyclostasa Elliott ex Schleiden (Fl. Gén. Env. Paris 2: 256, **1827**);
Lemna conjugata Willd. ex Schleiden (Linnaea 13: 391, **1839**);
Lemna minima Chev. ex Schleiden (Linnaea 13: 385-392, **1839**);
Lemna minuta Kunth ex Schleid. (**1839**)*
Lemna trichorrhiza Thuiller ex Schleid. (**1839**) in herb. (G - Genève, Switzerland)*;
Lemna minima Kunth (Enum. Pl. 3: 2-7, **1841**);
Lemna ovata A.Br. ex C.Krauss (Flora 28: 344, **1845**);
Lenticula minima Humb. & Kunth ex Miq. (**1855**)*;
Lenticula minima (Chev.) Kurz (J. Linn. Soc., Bot. 9: 266, **1866**);
Lemna minor var. *oxymitra* Hegelm. (Lemnac. 143, **1868**);
Lemna minor var. *colorata* Hegelm. (Lemnac. 144, **1868**);
Lenticularia monorbiza Montandon (Guide Bot. 308, **1868**);
Hydrophace minor (L.) Bubani (Fl. Pyren. 4: 23, **1901**);
Lemna minor var. *latiuscula* Domin (Sber. Kgl. Böhm. Gesell. Wiss. Prag, **1903**);
Lemna blatteri McCann (J. Bomb. Nat. Hist. Soc. 43 (2), **1942**);
Lemna minor II (in Landolt, Ber. Schweiz. Bot. Ges. 67: 271-410, **1957**);
Lemna monorrhiza Montandon ex Daubs (Illinois Biol. Monogr. 34, **1965**);
Lemna rwandensis De Sloover (Bull. Jard. Bot. Natl. Belg. 43: 366, **1973**);
Lemna elliptica Opiz in herb. (BR - Meise, Belgium)*;
Lemna macrorrhiza Pers. in herb. (MO - Saint Louis, Missouri, USA)*;

***Lemna minuta* Kunth (Nov. Gen. Sp. 1: 372, 1817)**

Lemna minima Chev. (Fl. Gén. Env. Paris 2: 256, **1827**);
Lemna minima Phil. (Linnaea 29: 1-47, **1857**);
Lemna minima Humb. ex Phil. (**1865**)*;
Lemna valdiviana var. *minima* Hegelm. (Lemnac. 138, **1868**);
Lemna valdiviana var. *abbreviata* Hegelm. (Fl. Bras. 3(2): 19, **1878**);
Lemna abbreviata (Hegelm.) Hegelm. (Bot. Jahrb. Syst. 21: 298, **1895**);

Lemna minima (Hegelm.) Phil. ex Hegelm. (Bot. Jahrb. Syst. 21: 299, 1895);
Lemna paludicola Kiener (1941)*;
Lemna minuscula Herter (Revista Sudamer. Bot. 9: 185, 1954);
Lemna abbreviata Reineck in herb. (LY - Lyon, France)*;
Lemna reticulata Phil. in herb. (BR - Meise, Belgium; STU - Stuttgart, Germany)*

***Lemna obscura* (Austin) Daubs (Illinois Biol. Monogr. 34: 20, 1965)**

Lemna minor var. *obscura* Austin (Manual ed. 5: 479, 1867);
Lemna minor var. *orbiculata* Austin (Manual ed. 5: 479, 1867);
Lemna minor var. *colorata* (Lemnac. 144, 1868);
Lemna ecuadoriensis Landolt (Veröff. Geobot. Inst. ETH Stiftung Rübel Zürich 70: 22, 1980);
Lemna gibba var. *americana* Austin in herb. (STU - Stuttgart, Germany)*;
Lemna gibboides Landolt*;
Lemna perpusilla var. *subsolida* Austin in herb. (STU - Stuttgart, Germany)*

***Lemna perpusilla* Torr. (Fl. New York 1: 245, 1843)**

Lemna perpusilla var. *trinervis* Austin (Manual ed. 5: 479, 1867);
Hydrophace perpusilla (Torr.) Lunell (Amer. Midl. Naturalist 4: 237, 1915);
Lemna trinervis auct.*

***Lemna tenera* Kurz 1871**

Staurogeton tener (Kurz) (Tzvelev, Bot. Zhurn. (Moscow & Leningrad) 84(7): 114, 1999)

***Lemna trisulca* L. (Sp. Pl. 970, 1753)**

Hederula aquatica Lobel (1579)*;
Lenticula aquatica trisulca C.Bauhin (1623)*;
Lenticula aquatica trisulca Hill (1757)*;
Lenticula trisulca (L.) Scop. (Fl. Carniol. ed. 2, 2: 213, 1772);
Lenticula ramosa Lam. (Fl. Franç. 2: 189, 1779);
Lemna cruciata Roxb. (Fl. Ind. ed. 1832 3: 566, 1832);
Lemna intermedia Ruthe (Fl. Mark Brandenburg ed. 2: 277, 1834);
Staurogeton trisulcus (L.) Schur (Verh. Mitth. Siebenbürg. Vereins Naturwiss. Hermannstadt 4: 70, 1853);
Lemna bisulca Veesenm. (Beitr. Pflanzenk. Russ. Reiches 9: 104, 1854);
Lenticula cruciata Roxb. ex Miq. (1855)*;
Staurogeton trisulcum Montandon (Guid. Bot. 308, 1868);
Lemna trisulca var. *pigmaea* Henn. (Verh. Bot. Vereins Prov. Brandenburg 33: 8, 1891);
Hydrophace trisulca (L.) Bubani (Fl. Pyren. 4: 23, 1901);
Lemna trisulca var. *linearis* Asch. & Graebn. (Syn. Mitt. Eur. Fl. 2: 392, 1904);
Lemna trisulca var. *sagittata* Makino (J. Jap. Bot. 3: 10, 1926)

***Lemna turionifera* Landolt (Aquatic Bot. 1: 355, 1975)**

Lemna minor var. *oxymitra* Hegelm. (Lemnac. 143, 1868);
Lemna minor var. *colorata* Hegelm. (Lemnac. 144, 1868);
Lemna minor I (in Landolt, Ber. Schweiz. Bot. Ges. 67: 271-410, 1957)

***Lemna valdiviana* Phil. (Linnaea 33: 239, 1864)**

Lemna minuta Raf. (Med. Repos. Original Essays Intelligence Phys. 5: 353, 1808);
Lemna minor var. *cyclostasa* Elliott (Sketch Bot. S. Carolina 2: 518, 1824);
Lemna torreyi Austin (Manual ed. 5: 479, 1867);
Lemna valdiviana var. *pellucida* Hegelm. (Lemnac. 138, 1868);
Lemna valdesiana S.Watson (U.S. Geol. Expl. 40th parallel 336, 1871);
Lemna valdiviana var. *platyclados* Hegelm. (Fl. Bras. 3(2): 20, 1878);
Lemna platyclados (Hegelm.) Hegelm. (Bot. Jahrb. Syst. 21: 298, 1895);
Lemna valdiviana var. *robusta* Hegelm. (Bot. Jahrb. Syst. 21: 298, 1895);
Lemna cherokeensis Schwein. ex Hegelm. (Bot. Jahrb. Syst. 21: 298, 1896);

Lemna cyclostasa Elliott ex W.Thomps. (Rep. (Annual) Missouri Bot. Gard. 9: 35, 1898);
Lemna aequilatera Hegelm. in herb. (STU - Stuttgart, Germany)*;
Lemna membranacea Hegelm. in herb. (STU - Stuttgart, Germany)*;
Lemna valdiviana f. *gigantea* Hegelm. in herb. (STU - Stuttgart, Germany)*

***Lemna yungensis* Landolt (Bull. Geobot. Inst. ETH 64: 18, 1998)**

no synonym known

***Spirodela intermedia* W.Koch (Ber. Schweiz. Bot. Ges. 41: 114, 1932)**

Lemna polyrrhiza var. *maxima* Griseb. (1879);
Spirodela biperforata W.Koch (Ber. Schweiz. Bot. Ges. 42: 188, 1933);
Lemna montevidensis Phil. in herb. (LY - Lyon, France)*

***Spirodela polyrrhiza* (L.) Schleid. (Linnaea 13: 392, 1839)**

Lemna polyrrhiza L. (Sp. Pl. 970, 1753);
Lenticula major Hill (Brit. Herb.: 531, 1757);
Lenticula polyrrhiza (L.) Lam. (Fl. Franç. 2: 189, 1779);
Lemna orbicularis Kit. ex Schult. (Oestr. Fl. ed. 2, 1: 64, 1814);
Lemna obcordata P.Beauv. (J. Phys. Chim. Hist. Nat. Arts 82: 113, 1816);
Lemna thermalis P.Beauv. (J. Phys. Chim. Hist. Nat. Arts 82: 102, 113, 1816);
Lemna thermalis P.Beauv. ex Nutt. (Gen. N. Amer. Pl. 1: 19, 1818);
Lemna major C.A.Mey. (Ind. Cauc., 1831);
Lemna orbiculata Roxb. (Fl. Ind. ed. 1832 3: 565, 1832);
Lemna banatica Waldst. & Kit. ex Schleid. (Linnaea 13: 392, 1839);
Telmatophace polyrrhiza (L.) Godr. (Fl. Lorraine 3: 18, 1844);
Lemna major Griff. (Not. Pl. Asiat. 3: 216, 1851);
Telmatophace orbicularis (Kitt. ex Schult.) Schur (Verh. Mitth. Siebenbürg. Vereins Naturwiss. Hermannstadt 4: 70, 1853);
Lemna transilvanica Schur (Enum. Pl. Transsilv. 635, 1866);
Lemna polyrrhiza var. *concolor* Kurz (J. Bot. 5: 115, 1867);
Spirodela atropurpurea Montandon (Guide Bot. 309, 1868);
Lemna umbonata A.Br. ex Hegelm. (Lemnac. 156, 1868);
Lemna polyrrhiza var. *parva* Asch. & Graebn. (Synop. Mitteleurop. Fl. 2(2): 395, 1904);
Lemna polyrrhiza var. *magna* Asch. & Graebn. (Synop. Mitteleurop. Fl. 2(2): 395, 1904);
Lemna maxima Blatt. & Hallb. (J. Indian Bot. 2: 49, 1921);
Spirodela maxima (Blatt. & Hallb.) McCann (J. Bombay Nat. Hist. Soc. 43: 158, 1942);
Spirodela polyrrhiza var. *masonii* Daubs (Illinois Biol. Monogr. 34: 13, 1965)

***Wolffia angusta* Landolt (Veröff. Geobot. Inst. ETH Stiftung Rübel Zürich 70: 29, 1980)**

no synonym known

***Wolffia arrhiza* (L.) Horkel ex Wimm. (Fl. Schles. ed. 3: 140, 1857)**

Lemna arrhiza L. (Mant. Pl. 2: 294, 1771);
Lenticula arrhiza (L.) Lam. (Fl. Franç. 2: 190, 1779);
Lemna arrhiza Mich. ex Schleiden (Linnaea 13: 385-392, 1839);
Wolffia michelii Schleid. (Beitr. Bot. 233, 1844);
Wolffia delilii Miq. (Ned. Kruidk. Arch. 3: 429, 1855);
Bruniera vivipara Franch. (Billotia 1: 25, 1864);
Lemna microscopica Schur (Enum. Pl. Transsilv. 635, 1866);
Telmatophace arrhiza Schur (Enum. Pl. Transsilv. 635, 1866);
Horkelia arrhiza (L.) Druce (Fl. Berkshire 511, 1898)

***Wolffia australiana* (Benth.) Hartog & Plas (Blumea 20: 151, 1972)**

Wolffia arrhiza var. *australiana* Benth. (Fl. Austral. 7: 162, 1878);
Wolffia hegelmaieri F.Muell. in herb. (STU - Stuttgart, Germany)*

***Wolffia borealis* (Engelm. ex Hegelm.) Landolt (Veröff. Geobot. Inst. ETH Stiftung Rübel Zürich 44: 137, 1977)**

Wolffia brasiliensis var. *borealis* Engelm. ex Hegelm. (Lemnac. 127, 1868);

Wolffia punctata auct. amer*

***Wolffia brasiliensis* Wedd. (Ann. Sci. Nat., Bot. III, 12: 170, 1849)**

Wolffia punctata Griseb. (Fl. Brit. W. I. 512, 1864);

Grantia brasiliensis (Wedd.) MacMill. (Metasp. Minnesota Valley 134, 1892);

Wolffia papulifera C.H.Thomps. (Rep. (Annual) Missouri Bot. Gard. 1898: 40, 1898);

Bruniera punctata Nieuwl. (Amer. Midl. Naturalist 2: 306, 1912)

***Wolffia columbiana* H.Karst. (Bot. Unters. 1: 103, 1865)**

Grantia columbiana (H.Karst.) MacMill. (Metasp. Minnesota Valley 135, 1892);

Bruniera columbiana Nieuwl. (Amer. Midl. Naturalist 2: 306, 1912);

Wolffia robbinsii Austin in herb. (PH - Philadelphia, Pennsylvania, USA);

Wolffia vesciculosa Austin in herb. (STU - Stuttgart, Germany)

***Wolffia cylindracea* Hegelm. (Lemnac. 123, 1868)**

no synonym known

***Wolffia elongata* Landolt (Veröff. Geobot. Inst. ETH Stiftung Rübel Zürich 70: 27, 1980)**

no synonym known

***Wolffia globosa* (Roxb.) Hartog & Plas (Blumea 18: 367, 1970)**

Lemna globosa Roxb. (Fl. Ind. ed. 1832 3: 565, 1832);

Grantia globosa (Roxb.) Griff. (Hort. Suburb. Calcutt. 692, 1845);

Wolffia schleideni Miq. (Ned. Kruidk. Arch. 3: 428, 1855);

Wolffia delilii Kurz (J. Linn. Soc. Bot. 9: 265, 1866);

Wolffia delilii var. *schleideni* Kurz (J. Linn. Soc. Bot. 9: 265, 1866);

Thelmatophace cylindracea Welw. ex Hegelm. (Lemnac. 123, 1868);

Wolffia cylindracea Hegelm. (Lemnac. 123, 1868)

***Wolffia microscopica* (Griff.) Kurz (J. Linn. Soc., Bot. 9: 265, 1866)**

Grantia microscopica Griff. (Hort. Suburb. Calcutt. 692, 1845)

***Wolffia neglecta* Landolt (Ber. Geobot. Inst. E. T. H. Stiftung Rübel 60: 147, 1994)**

no synonym known

***Wolffiella caudata* Landolt (Ber. Geobot. Inst. E. T. H. Stiftung Rübel 58: 121, 1992)**

no synonym known

***Wolffiella denticulata* (Hegelm.) Hegelm. (Bot. Jahrb. Syst. 21: 305, 1895)**

Wolffia denticulata Hegelm. (Lemnac. 133, 1868)

***Wolffiella gladiata* (Hegelm.) Hegelm. (Bot. Jahrb. Syst. 21: 304, 1895)**

Wolffia gladiata Hegelm. (Lemnac. 133, 1868);

Wolffia gladiata var. *floridana* J.D.Sm. (Bull. Torrey Bot. Club 7: 64, 1880);

Wolffia floridana (J.D.Sm.) O.D.Sm. ex Hegelm. (Bot. Jahrb. Syst. 21: 305, 1895);

Wolffiella floridana (J.D.Sm.) Thomps. (Rep. (Annual) Missouri Bot. Gard. 1898: 37, 1898)

***Wolffiella hyalina* (Delile) Monod (Mém. Soc. Hist. Nat. Afrique N Hors-ser. 2: 242, 1949)**

Lemna hyalina Delile (Descr. Egypte, Hist. Nat. 4: 27, 1813);

Wolffia delilei Schleid. (Linnaea 13: 390, 1839);

Wolffia hyalina (Delile) Hegelm. (Lemnac. 128, 1868);

Wolffiella monodii Ast (Bull. Inst. Fondam. Afrique Noire, Sér. A, Sci. Nat. 30: 837, 1968);

Pseudowolffia hyalina (Delile) Hartog & Plas (Blumea 18: 366, 1970);

Pseudowolffia monodii (Ast) Hartog & Plas (Blumea 18: 366, 1970)

***Wolffiella lingulata* (Hegelm.) Hegelm. (Bot. Jahrb. Syst. 21: 303, 1895)**

Wolffia lingulata Hegelm. (Lemnac. 132, 1868)

***Wolffiella neotropica* Landolt (Veröff. Geobot. Inst. ETH Stiftung Rübel Zürich 70: 26, 1980)**

no synonym known

***Wolffiella oblonga* (Phil.) Hegelm. (Bot. Jahrb. Syst. 21: 303, 1895)**

Lemna oblonga Phil. (Linnaea 29: 45, 1858);

Wolffia oblonga (Phil.) Hegelm. (Lemnac. 131, 1868);

Wolffia lingulata var. *minor* Hegelm. (Fl. Bras. 3(2): 10, 1878);

Wolffia gladiata var. *abbreviata* Kurtz (1891) in herb. (CORD - Córdoba, Argentina)*;

Wolffia oxyphylla Spegazzini in herb. (INTA - Castelar, Argentina)*;

Wolffiella kurtzii Thompson in herb. (KANU - Lawrence, Kansas, USA)*

***Wolffiella repanda* (Hegelm.) Monod (Mém. Soc. Hist. Nat. Afrique N Hors-ser. 2: 242, 1949)**

Wolffia repanda Hegelm. (J. Bot. 3: 114, 1865);

Pseudowolffia repanda (Hegelm.) Hartog & Plas (Blumea 18: 366, 1970)

***Wolffiella rotunda* Landolt (Veröff. Geobot. Inst. ETH Stiftung Rübel Zürich 70: 26, 1980)**

no synonym known

***Wolffiella welwitschii* (Hegelm.) Monod (Mém. Soc. Hist. Nat. Afrique N Hors-ser. 2: 229, 1949)**

Wolffia welwitschii Hegelm. (J. Bot. 3: 113, 1865);

Wolffia congensis Welw. ex Trimen (J. Bot. 4: 223, 1866);

Wolffiopsis welwitschii den (Hegelm.) Hartog & Plas (Blumea 18: 366, 1970);

Lemna revoluta L.A.Richard in herb. (STU - Stuttgart, Germany)*