Initial decomposition of floating leaf blades of *Nymphoides peltata* (S.G. Gmel.) O. Kuntze: causes, impacts and succession

Peter F. Klok · Gerard van der Velde

P. F. Klok · G. van der Velde (✉)
Department of Animal Ecology and Physiology, Radboud Institute for Biological and Environmental Sciences (RIBES), Radboud University, Nijmegen, The Netherlands
e-mail: g.vandervelde@science.ru.nl

P. F. Klok
Department of Particle Physics, Institute for Mathematics, Astrophysics and Particle Physics (IMAPP), Radboud University, Nijmegen, The Netherlands

G. van der Velde
Naturalis Biodiversity Center, Leiden, The Netherlands

Abstract

Background. During a study on the outdoor floating leaf blade production of *Nymphoides peltata* (S.G. Gmel.) O. Kuntze (Fringed Water Lily), ~~their~~ initial leaf blade decomposition was studied simultaneously by measuring infected, damaged and lost area of floating leaf blades.

Methods. Data ~~of~~ on initial decomposition over time were collected for all leaves during one growth season in four plots: two in outdoor mesocosms and two in an oxbow lake. Each leaf was tagged uniquely upon appearance in a plot. The vegetation in the mesocosms differed with respect to plant species, one contained a mono-culture of *N. peltata* and the other *N. peltata* associated with *Glyceria fluitans* (L.) R. Br. and *G. maxima* (Hartm.) Holmb. The lake plots were situated within a monospecific *N. peltata* stand, differing in depth and position within the stand. Leaf length, visually estimated percentages of damaged area for each damage type, and decay of the tagged leaves were recorded bi-weekly. When the leaf blades sunk under the water surface or disappeared completely, they were no longer followed. Under water the ~~leaf~~ leaves decayed and were~~was~~ consumed by snails completely, so contributing to the detritus food chain.

Results. The observed causes of damage on floating leaves were consumption and/or damage by waterbirds (*Fulica atra*), pond snails, caterpillars (*Elophila nymphaeata, Cataclysta lemnata*), chironomid larvae (*Cricotopus trifasciatus*), infection by a phytopathogenic fungus (*Septoria villarsiae*), senescence by autolysis, and microbial decay. The impact on leaf loss and succession is described for the causes found.

Comment [C1]: I did not understand this wording. Do you mean something like"Successional changes in causes of leaf decomposition and impacts of different causes are discussed"

Keywords: Enclosure, Herbivores, Laminae, Mesocosm, Nymphaeid growth form, Senescence, Succession of decomposition causes

Introduction

Aquatic macrophytes can be considered as the basic frame of wetland ecosystems, called macrophyte-dominated systems (Den Hartog & Van der Velde 1988, Jeppesen, Søndergaard & Christoffersen 1998). The nymphaeid macrophyte, a growth form represented by species of Nymphaeaceae, Menyanthaceae, Potamogetonaceae, Polygonaceae and Aponogetonaceae, forms the base of nymphaeid-dominated systems (Van der Velde 1980). This growth form is characterized by floating leaves, flowers on or elevated above the water surface and roots in the sediment of shallow open waters or littoral borders (Luther 1983, Van der Velde 1981).

In shallow freshwater lakes, *Nymphoides peltata* can cover large areas (e. g. Brock, Van der Velde & Van de Steeg, 1987), where submerged plants disappeared by accumulation of organic matter on the sediment during succession, eutrophication and acidification (Arts et al. 1990; Wiik et al. 2015).

Comment [C2]: I did not understand this part of the sentence. Why would submerged plants disappear due to accumulation of organic matter on the sediment? Do you mean that submerged plants died due to shading by Nymphoides, resulting in accumulation of dead plant matter on the sediment surface? Or do you mean that dead leaves of Nymphoides dropped onto submerged aquatic vegetation, smothering it and resulting in build up of organic matter on the sediment?

Information about distribution, growth form, importance of floating leaves, habitat and environmental conditions of *N. peltata* (Fig. 1) is given in Klok & Van der Velde (2022).

Decomposition of floating leaf blades

Decomposition of leaves in natural conditions (Fig. 2) involves a complex set of interacting processes, which can be roughly classified into internal (physiological) and external (abiotic or biotic) processes (Van der Velde et al. 1982, Kok 1993). At first only host specific species – more or less specialized and often restricted to particular plant taxa – are able to break through the defense system to consume fresh plant tissue. At a later stage, when the defense system has been weakened, other species colonize the leaves.

Decomposition of young leaf blades of *N. peltata* already starts under water before they unroll with consumption and/or damage. During initial decomposition, when leaves are still floating, macrophyte tissue is used by herbivores and by phytopathogenic and saprotrophic microorganisms. Various causes and stages of decomposition can be recognized on a single leaf. Damage of leaves can induce the leaching of soluble carbohydrates such as oligosaccharides and starch, proteinaceous and phenolic compounds, some of which can be rapidly metabolized by microorganisms. Finally, plant tissue senesces by autolysis, colouring yellow by the resorption of chlorophyll, followed by further decomposition initiated by weak pathogens and facultative herbivores, leading to the production of debris and fecal pellets. The chemical composition of plant tissue also changes during autolysis due to hydrolysis of macromolecules (which may weaken tissue structure), resorption of nutrients (like N and P, as well as carbon compounds such as starch) and loss of secondary compounds. Furthermore, leaves are colonized by microorganisms, causing microbial enrichment which makes the tissue more attractive for detritivorous macroinvertebrates. Decayed floating leaves sink underwater to the bottom, where they provide a resource for detritus-based benthic food webs during further decomposition (Klok & Van der Velde 2019). To study the latter decomposition process, the litterbag method is commonly used (Brock et al. 1982, Brock 1985, Wieder & Lang 1982). As *N. peltata* only grows in alkaline water (Van der Velde, Custers & De Lyon 1986, Smits et al. 1988) and development of floating leaves is dependent on calcium uptake of this plant, decomposition is studied only in alkaline water (Smits, Schmitz & Van der Velde 1992).

Comment [C3]: How is this known? References should be cited for previous work on this topic.

Comment [C4]: Cite reference

Comment [C5]: Reference?

Research questions

The present study covers initial decomposition of floating leaves of *Nymphoides peltata* (S.G. Gmel.) O. Kuntze in different water bodies by investigating the effects of damage causes found on floating leaves. Together with the complementary study about the production of floating leaves (Klok & Van

Comment [C6]: It seems that this general topic was already studied by Van der Velde G, Van der Heijden LA. 1985. That previous study should be introduced here and here is should be explained what further new information will be presented in the present study.

der Velde 2022) it describes the life and plasticity of floating leaves of *Nymphoides peltata* under different environmental circumstances. This study deals with the following questions:

1) What are the causes and patterns of initial decomposition of floating leaves?
2) What is their impact on leaf properties?
3) How does initial decomposition progress during the season and is there a succession of causes?
4) Which factors make the leaves susceptible for decomposition?

Comment [C7]: This is an important question but was not addressed by your experiment. This question should not be listed among the others which were addressed by your student. This question could still be discussed in the Discussion section although your study makes no concrete contribution towards addressing this question.

Materials and Methods

Sites

Research took place in four plots two in outdoor mesocosms and two in an oxbow lake, each with a size of 50x50 cm (Klok & Van der Velde 2022) (Table 1).

Potential, actual and photosynthetic leaf area

A distinction was made between potential, actual and photosynthetic leaf area. The potential area is defined as the area of an entirely intact leaf, the actual area as the potential area minus the area missing and the photosynthetic area as the remaining green part of the actual area.

Regression equation for calculating leaf area

The potential leaf area was calculated from leaf length and leaf width and is described mathematically by equation (1), which has been determined by previous research (Van der Velde et al. 1982):

$$A(L,W) = 1.028 * \pi * \left(\frac{L+W}{4}\right)^2 \qquad (1)$$

where: $A(L,W)$ = potential leaf area at length L and width W (mm^2)

L = leaf length (mm)

W = leaf width (mm)

1.028 = correction factor (the leaves are not circular)

Field data

The initial leaf decomposition of *N. peltata* floating leaf blades ~~has been~~was studied in the same plots and at the same time as the leaf production as described in Klok & Van der Velde (2022). Initial decomposition data included visually estimating both leaf damage and decomposition per cause as percentage of the potential leaf area of each leaf. Several types of damage and their causes have been distinguished and described earlier (Lammens & Van der Velde 1978, Van der Velde 1979).

Comment [C8]: I think it is important to include this, otherwise you would need to describe in Methods how you determined the fungus species as well as the invertebrate species. I assume this is described in the references cited here.

Results

Floating leaf data

Floating leaf information, comprising total number of leaves, total potential leaf area, leaf life span, growth period and vegetation period, is shown per plot in Table 2. The combination over time of total number of leaves and total potential leaf area is shown per plot (Fig. 3).

Unfortunately, data of the first weeks in 1978 were missing for CT1 and CT2. Fortunately, the growing season of *N. peltata* started on the same date both in 1978 and in 1979, so data of the first weeks of 1979 for CT1 and CT2 have been used to give an indication of number of leaves and leaf area at the start of the season.

Causes and patterns of initial decomposition

All causes and stages of initial decomposition found in this study are described below:

Consumption and damage by waterfowl. Consumption of leaf tissue by coots (*Fulica atra* L., Rallidae) occurred in the lake plots only and can be recognized by missing parts in the form of triangular areas at the margin of leaves. Sometimes major parts of leaves are consumed. Prints of the beak are visible around the consumed areas.

Consumption by pond snails. A major cause of damage on fresh leaf tissue in all plots ~~is~~ was caused by *Lymnaea stagnalis* (L.) (Lymnaeidae, Gastropoda) by consuming parts of young leaves under water, resulting in rows of holes in the unrolled leaf blades, large near the edge and smaller towards the center of the leaf. To a lesser extend other lymnaeid species and other freshwater pulmonate snails ~~are~~ were involved, showing a preference for decaying leaf material, in particular areas infected by fungi.

Consumption and damage by aquatic caterpillars of moths. The caterpillars of the moths *Elophila nymphaeata* (L.), Crambidae, Lepidoptera (brown china-mark, lake plots only) (Gaevskaya 1969, Lammens & Van der Velde 1978) and *Cataclysta lemnata* (L.), Crambidae, Lepidoptera (small china-mark, tank plots only) damaged floating leaves in two ways: by leaf tissue consumption and by cutting out oval leaf patches that are used for shelter (Van der Velde 1979). Floating shelters are created either by attaching a patch to the underside of a floating leaf or by spinning two patches together (*Elophila*), or by constructing a floating case by various materials, in particular small leaf pieces (*Cataclysta*).

Mining by chironomid larvae. Larvae of the midge *Cricotopus trifasciatus* Mg., Chironomidae, Diptera, were observed to mine their way through the leaf tissue by consuming particular tissue layers while leaving the lower epidermis unaffected (halfminer) (Lammens & Van der Velde 1978). They occurred in the lake plots only (Fig. 4).

Infection by phytopathogens. Leaves were infected in all plots by the fungus *Septoria villarsiae* Desm., Mycosphaerellaceae, Capnodiales, the causative agent of a leaf spot disease (Fig. 5). Asexual spores (conidia) are produced in conidiomata (black spherical structures) (Fig. 6).

Autolysis. Autolysis occurred in all plots and is visible by the change in leaf color from green to yellow, indicating that chlorophyll is degraded.

Microbial decay. The resistance of a leaf against microbial infection disappears quickly due to erosion of the wax layer and autolysis, facilitating microbial decay in all plots, which ~~is~~ was indicated by a change in leaf color from yellow to brown and the softening of the leaf tissue by maceration. ~~By~~ During microbial decay, ~~they sink~~leaves sunk under the water surface.

In tank plots CT1 and CT2 loss and damage by *Cataclysta lemnata*, pond snails, *Septoria villarsiae*, autolysis and microbial decay occurred. Bemmelse Strang lake plots BS1 and BS2 suffered from loss and damage by *Fulica atra*, pond snails, *Elophila nymphaeata*, *Cricotopus trifasciatus*, *Septoria villarsiae*, autolysis and microbial decay. Fig. 7 shows the relative contributions to initial decomposition of all causes in all plots.

Impact of causes

The impact of initial decomposition causes on leaves for all plots is shown in Table 3. Autolysis and microbial decay are the main decomposition causes. Generally, initial decomposition caused by animals was a very small part of the total potential floating leaf area in all plots, since *N. peltata* leaves disappear under water rather soon after autolysis and cell death ~~for further decomposition~~ and ~~are~~ were thus lost for measurement of further decomposition. The combination of number of leaves and total potential leaf area clearly shows that in the second half of the growth period the tank plots produced smaller leaves, in contrast to the lake plots, as described in Klok & Van der Velde (2022).

For all plots the absolute and relative loss by damage causes of photosynthetic leaf area over time is shown (Fig. 8) with the impact of damage causes (Table 3).

The order of impact of damage causes from high to low, based on average percentages of the total potential area affected, is per plot:

- CT1: autolysis, *Septoria*, microbial decay, snails, *Cataclysta*,
- CT2: autolysis, microbial decay, *Septoria*, snails, *Cataclysta*,
- BS1: *Cricotopus*, microbial decay, autolysis, *Fulica*, snails, *Elophila*, *Septoria*,

- BS2: microbial decay, *Cricotopus*, autolysis, *Fulica*, snails, *Septoria*, *Elophila*.

The impact of initial decomposition damage (= loss of photosynthetic leaf area) per cause over time for the plots is shown in Fig. 9 (plot CT1), Fig. 10 (plot CT2), Fig. 11 (plot BS1) and Fig. 12 (plot BS2). All figures use the same scale for proper comparison.

The minor damage causes *Cataclysta*, *Elophila*, *Septoria* and snails are also shown with an enlarged Y-scale to ~~be able to see~~ display more details (Fig. 13). For *Cataclysta*, *Cricotopus*, *Elophila* and *Septoria* the damage increments are shown along with the total damage over time (Fig. 14, Fig. 15, Fig. 16, Fig. 17). The development of several large generations of midge and moths can be seen (Fig. 9 through Fig. 17). Not all generations exist parallel in time. For *Cataclysta*, *Cricotopus*, *Elophila* and *Septoria* the summation of the increments is shown for all plots (Fig. 18).

The percentage of leaves affected in the tank plots had some variation (91.0 and 95.6 %), which was slightly lower than in the lake plots (96.4 and 97.0 %). The average percentage of potential leaf area affected was stable: high for the tank plots (84.15 and 84.53 %) and low for the lake plots (23.23 and 23.75 %).

Comment [C9]: Does this paragraph refer to only the minor causes of damage listed in the previous paragraph or all causes of damage? Please specify at the start of this paragraph.

Succession of causes

The succession of damage causes, based on first occurrence, is per plot:

- CT1 (mixed): autolysis, microbial decay, snails, *Septoria*, *Cataclysta*,
- CT2 (monospecific): autolysis, microbial decay, snails, *Septoria*, *Cataclysta*,
- BS1 (center): *Cricotopus*, microbial decay, autolysis, snails, *Elophila*, *Fulica*, *Septoria*,
- BS2 (border): *Cricotopus*, snails, autolysis, microbial decay, *Elophila*, *Septoria*, *Fulica*.

The above succession lists show that the tank plots (CT1, CT2) have the same succession order, while the lake plots (BS1, BS2) have quite a different order.

Influences on susceptibility

Comment [C10]: This is Discussion not Results. Please integrate into the Discussion section

Prolonged cloudy and wet weather are supposed to impose stress on *Nymphoides* by weakening the defense of leaves due to reduced solar radiation, and thus promoting heavy infection and damage by phytopathogens (Van der Aa 1978). Leaf blades contain phenolics with fungistatic properties (Smolders et al. 2000) and poor light conditions reduce the content of phenolics in leaf tissue (Vergeer & Van der Velde 1997), which makes mature leaves vulnerable to infection.

Discussion

Unfortunately, due to the fact that the four locations did not contain multiple plots, it is useless to apply statistics for firm conclusions.

Comment [C11]: Reword – the reviewer has suggested alternative wording.

Differences between plots

The number of leaves in the tank plots was considerably higher and the size of leaves considerably smaller compared to the lake plots (Table 2) (Klok & Van der Velde 2022). This can be explained by the limited space and by the limited nutrient availability in the tank plots. At a higher degree of enclosure more and smaller leaves appeared, compared to a low degree of enclosure (Klok & Van der Velde (2022) and literature therein).

Compared to the center plot in the lake, the border plot has a higher nutrient availability through continuous supply via water currents, which counts for ~~less~~fewer, but larger leaves.

Comment [C12]: I didn't understand this wording. Do you mean "promotes the growth of "?

The tank plots showed a decrease in leaf area over time after a maximum at the start of the season. Due to the sudden inundation of river water in early spring, the reaching of such a maximum was disrupted in the lake plots. This resulted in a later maximum, which was lower for the center plot due to limited nutrients and much higher for the border plot with much less leaves and almost unlimited nutrients.

The absence of waterfowl in the tank plots ~~is obvious~~was expected, since the plots were covered with a frame with chicken wire. The occurrence of the moth *Cataclysta* in the tank plots ~~is~~ was due to introduction with *Lemna* in the past, while the moth *Elophila* occurred in the lake plots. The midge in the lake plots (*Cricotopus*) probably exists in larger water volumes only where wind and wave action provide the larvae with oxygen. Infection by the fungus (*Septoria*) was very high in the tank plots and low in the lake plots, which could be caused by the combination of high leaf density and low nutrient availability in the tank plots.

The average percentage of potential leaf area affected, high for the tank plots and low for the lake plots, ~~is~~ was caused by the very low infection by *Septoria* in the lake plots compared to the tank plots and possibly by the high leaf density and the low nutrient availability in the tank plots. Snails had a large impact in one tank plot.

Incremental damage ~~is~~ was higher for CT1 and BS1 compared to CT2 and BS2, respectively, except for *Cataclysta*.

Senescence

Newly unrolled floating leaf blades are fully green and hydrophobic due to a thick epicuticular wax layer. This layer gradually erodes during senescence and as cellulolytic and other bacteria and fungi colonize the leaf tissue (Howard-Williams et al. 1978, Robb et al. 1979, Rogers & Breen 1981, Barnabas 1992). Senescence starts shortly after the first leaves are fully grown and continues throughout the growth period. During senescence the leaves turn from green to yellow by autolysis, an orderly physiological process controlled by the plant itself, and ultimately turn to brown. Concomitant microbial decay softens the leaves.

Van der Velde & Van der Heijden (1985) analyzed the relative increase of different damage and decomposition types at different age classes (each class 5 days) of the floating leaves of *N. peltata* in the same plots as used in this study. They compared the results between the concrete tanks (two plots together) and the Bemmelse Strang (two plots together). Patterns of occurrence of the decomposition types over leaf age classes shows clearly that young leaves are damaged already when they appear at the water surface in the case of *Cataclysta lemnata*, (age 1-9, peak at age 3) and *Elophila nymphaeata* (age 1-7, peak at age 1), *Cricotopus trifasciatus* (age 1-13, peak at age 4) snails (age 1-9 CT, peak at age 6 and BS age 1-9, peak at age 1) and Coots (*Fulica atra*) (age 1-10, peak at age 2). *Septoria villarsiae* started in the concrete tanks at leaf age 1 with a peak at age 4-5 (leaf age 1-11), while in the Bemmelse Strang it started at leaf age 4 with peak at age 11 leaf age 4-13. Yellow areas started in both waters at age 1 with peak at 5 (CT 1-7, BS 1-9). Decayed areas replaced the yellow ones at leaf age 1-11 with a peak at age 8 in the case of the concrete tanks and at leaf age 1-13 with a peak at age 12 in the case of the Bemmelse Strang.

Comment [C13]: What does this mean?

From these results we can conclude that the herbivores prefer young leaves as food. Yellow and decayed areas showed a similar course and peaked after each other. The ~~most clearly~~clearest difference was the timing of *Septoria*~~, which~~ infection, which started early in young leaves in the concrete tanks but in the Bemmelse Strang in older leaves.

Comment [C14]: This seems to contradict your claim in the Introduction (line 63) where you claim that young leaves are only utilized by specialist herbivores but more generalist and facultative herbivores prefer older leaves (line 73, 68)

Succession of causes

The succession of leaf decomposition causes, based on first occurrence, was exactly the same for both tank plots: autolysis was followed by microbial decay, snails, *Septoria* and finally *Cataclysta*.

For the lake plots this succession was different. Both plots started with *Cricotopus*, for the center plot followed by microbial decay, autolysis, snails, *Elophila*, *Fulica* and *Septoria*, and for the border plot followed by snails, autolysis, microbial decay, *Elophila*, *Septoria* and *Fulica*.

Primary underwater consumption of young leaves by snails may explain the different succession order in the lake plots for snails, autolysis and microbial decay. The late occurrence of microbial decay in the border plot may be explained by more available nutrients strengthening the leaf condition.

Comparison with other nymphaeids

The growth period of *N. peltata* in the plots lasted 155 to 171 days, or 85 to 93 % of the vegetation period of 169 to 202 days of the plots. The total loss of photosynthetic area of *N. peltata* was 99.9 % for CT1, 100.0 % for CT2, 53.1 % for BS1 and 60.5 % for BS2 (Table 2, Table 3).

From similar research on plots with *Nuphar lutea*, *Nymphaea alba* and *N. candida* (Klok & Van der Velde 2017, Klok & Van der Velde 2019), the growth period lasted 71 to 134 days, or 53 to 73 % of the vegetation period of 135 to 199 days. Percentages of loss of photosynthetic area ranged from 38 to 50 % for *Nuphar* and 44 to 54 % for *Nymphaea*.

The relatively long growing period for *N. peltata* can be explained by the lasting development of new leaves.

Comment [C15]: This reasoning seems circular. A growing period is defined based on continuing vegetative growth, so it cannot be explained by continuing vegetative growth.

Loss of leaf tissue tended to increase during the vegetation period of *Nuphar lutea* and *Nymphaea alba* from less than 20% of the total potential leaf area to more than 50%. Leaf area loss by damage of *Nymphaea candida* (HW) was less than 10% to almost 20%.

Comment [C16]: Do you mean potential photosynthetic leaf area, as defined in Methods?

Conclusions

Initial decomposition included the internal cause autolysis and external causes by animals, fungi and microbes. Animals included birds (*Fulica atra*), snails (mainly *Lymnaea stagnalis*), caterpillars of aquatic moths (*Cataclysta lemnata*, *Elophila nymphaeata*) and chironomid larvae (*Cricotopus trifasciatus*). The ascomycete *Septoria villarsiae* was the most important fungus. Autolysis and microbial decay were the main causes, while the other causes generally were marginal.

From high to low impact the order of initial decomposition causes was autolysis, *Septoria*, microbial decay, pond snails, *Cataclysta* for the tank plots and *Cricotopus*, microbial decay, autolysis, *Fulica*, pond snails, *Elophila*, *Septoria* for the lake plots.

The succession of causes per plot, based on first occurrence, was autolysis, microbial decay, snails, *Septoria*, *Cataclysta* for the tank plots and it was *Cricotopus*, microbial decay, autolysis, snails, *Elophila*, *Fulica*, *Septoria* for the center lake plot and *Cricotopus*, snails, autolysis, microbial decay, *Elophila*, *Septoria*, *Fulica* for the border lake plot.

Factors that influence leaf condition and thus allow initial decomposition are senescence, decrease of nutrient availability and cloudy and rainy weather conditions.

Comment [C17]: This finding cannot be a conclusion based on the data presented in this study and therefore this should not be the final concluding statement.

Acknowledgements

We thank L. van der Heijden, P.M.M. Bexkens and P.A.J. van Grunsven for collecting and working out field data, E.L. Huijser (†) for making the field data digitally available, P.H.M. Charpentier for providing us with all necessary literature and O. Knoppers for checking the english language..

References

Arts GHP, Van der Velde G, Roelofs JGM, Van Swaay CAM. 1990. Successional changes in the soft-water vegetation of (sub)atlantic, sandy, lowland regions during this century. Freshwater Biology 24:287-294.

Barnabas AD. 1992. Bacteria on and within leaf blade epidermal cells of the seagrass *Thalassodendron ciliatum* (Forskk.) Den Hartog. Aquatic Botany 43:257-266.

Brock TCM. 1985. Ecological studies on nymphaeid water plants. PhD Thesis. Catholic University Nijmegen, 205 pp.

Brock TCM, Huijbregts CAM, Van de Steeg-Huberts MJHA, Vlassak MA. 1982. In situ studies on the breakdown of *Nymphoides peltata* (Gmel.) O. Kuntze (Menyanthaceae); some methodological aspects of the litter bag technique. Hydrobiological Bulletin 16(1):35-49.

Brock TCM, Van der Velde G, Van de Steeg HM. 1987. The effects of extreme water level fluctuations on the wetland vegetation of a nymphaeid-dominated oxbow lake in the Netherlands. In: J. Pokorny, O. Lhotský & P. Denny (eds.). Waterplants and wetland processes. Archiv für Hydrobiologie Beihefte, Ergebnisse der Limnologie/Advances in Limnology 27:57-73.

Den Hartog C, Van der Velde G. 1988. Structural aspects of aquatic plant communities. In: Symoens J.J., ed. Vegetation of inland waters. Handbook of vegetation science 15:113-153. Kluwer Academic Publishers, Dordrecht.

Gaevskaya NS. 1969. The role of higher aquatic plants in the nutrition of the animals of fresh-water basins. Volume I, II and III. Published by National Lending Library for Science and Technology, Boston Spa, Yorkshire, England, 629 pp.

Howard-Williams C, Davies BR, Cross RHM. 1978. The influence of periphyton on the surface structure of a *Potamogeon pectinatus* L. leaf (a hypothesis). Aquatic Botany 5:87-91.

Jeppesen E, Søndergaard M, Christoffersen K (eds.). 1998. The structuring role of submerged macrophytes in lakes. Ecological Studies 131:1-423. Springer-Verlag, New York, Berlin, Heidelberg.

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

Klok PF, Van der Velde G. 2019. Initial decomposition of floating leaf blades of waterlilies: causes, damage types and impacts. PeerJ 7:e7158 DOI 10.7717/peerj.7158.

Klok PF, Van der Velde G. 2022. Plant traits and environment: floating leaf blade production and turnover of *Nymphoides peltata* (S.G. Gmel.) O. Kuntze (Menyanthaceae). PeerJ 10:c13976 DOI 10.7717/peerj.13976.

Kok CJ. 1993. Decomposition of floating leaves of *Nymphaea alba* L. under alkaline and acid conditions. PhD thesis, University of Nijmegen. 121 pp.

Lammens, EHRR, Van der Velde G. 1978. Observations on the decomposition of *Nymphoides peltata* (Gmel.) O. Kuntze (Menyanthaceae) with special regard to the leaves. Aquatic Botany 4:331-346.

Luther H. 1983 On life forms, and above-ground and underground biomass of aquatic macrophytes. Acta Botanica Fennica 123:1-23.

Robb F, Davies BR, Cross R, Kenyon C, Howard-Williams C. 1979. Cellulolytic bacteria as primary colonizers of *Potamogeton pectinatus* L. (Sago pond weed) from a brackish south-temperate coastal lake. Microbial Ecology 5:167-177.

Rogers KH, Breen CM. 1981. Effects of periphyton on *Potamogeton pectinatus* L. leaves. Microbial Ecology 7:351-361.

Smits AJM, Schmitz GHW, Van der Velde G. 1992. Calcium-dependent lamina production of *Nymphoides peltata* (Gmel.) O. Kuntze (Menyanthaceae) –Implications for distribution. Journal of Experimental Botany 43(254):1273-1281.

Smits AJM, De Lyon MJH, Van der Velde G, Steentjes PLM, Roelofs JGM, 1988. Distribution of three nymphaeid macrophytes (*Nymphaea alba* L., *Nuphar lutea* (L.) Sm. and *Nymphoides peltata* (Gmel.) O. Kuntze) in relation to alkalinity and uptake of inorganic carbon. Aquatic Botany 32:45-62.

Smolders AJP, Vergeer LHT, Van der Velde G, Roelofs JGM. 2000. Phenolic contents of submerged, emergent and floating leaves of (semi-) aquatic macrophyte species. Why do they differ? Oikos 91:307-310.

Van der Aa HA. 1978. A leaf spot disease of *Nymphaea alba* in the Netherlands. Netherlands Journal of Plant Pathology 84:109-115.

Van der Velde G. 1979. *Nymphoides peltata* (Gmel.) O. Kuntze (Menyanthaceae), as a food plant for *Cataclysta lemnata* (L.) (Lepidoptera, Pyralidae). Aquatic Botany 7:301-304.

Van der Velde G. 1980. Studies in nymphaeid-dominated systems with special emphasis on those dominated by *Nymphoides peltata* (Gmel.) O. Kuntze (Menyanthaceae). Doctoral Thesis, Catholic University Nijmegen, 163 pp.

Van der Velde G. 1981. A project on nymphaeid-dominated systems. Hydrobiological Bulletin 15(3):185-189.

Van der Velde G, Van der Heijden LA, Van Grunsven PAJ, Bexkens PMM. 1982. Initial decomposition of *Nymphoides peltata* (Gmel.) O. Kuntze (Menyanthaceae), as studied by the leaf-marking method. Hydrobiological Bulletin 16 (1):51-60.

Van der Velde G, Van der Heijden LA. 1985. Initial decomposition of floating leaves of *Nymphoides peltata* (Gmel.) O. Kuntze (Menyanthaceae) in relation to their age, with special attention to the role of herbivores. Verhandlungen der Internationalen Vereinigung für theoretische und angewandte Limnologie 22:2937-2941.

Van der Velde G, Custers CPC, De Lyon M.H. 1986. The distribution of four nymphaeid species in the Netherlands in relation to selected abiotic factors. Proceedings of the European Weed Research Society/Association of Applied Biologists, 7th Symposium on Aquatic Weeds, Loughborough, UK, 1986, p. 363-368.

Vergeer LHT, Van der Velde G. 1997. The phenolic content of daylight-exposed and shaded floating leaves of water lilies (Nymphaeaceae) in relation to infection by fungi. Oecologia 112:481-484.

Wieder RK, Lang GE, 1982. A critique of the analytical methods used in examining decomposition data obtained from litter bags. Ecology 63 (6):1636-1642.

Wiik E, Bennion H, Sayer CD, Davidson TA, McGowan S, Patmore IR, Clarke SJ. 2015. Ecological sensitivity of marl lakes to nutrient enrichment, evidence from Hawer Water, UK. Freshwater Biology 60:2226-2247.