Natural England Commissioned Report NECR243

Development of a conservation plan for least water-lily *Nuphar pumila* in England 2017

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Foreword

Natural England commission a range of reports from external contractors to provide evidence and advice to assist us in delivering our duties. The views in this report are those of the authors and do not necessarily represent those of Natural England.

Background

Least water-lily *Nuphar pumila* is known from over 100 sites in Scotland, but only from Cole Mere in England, although it formerly occurred in other meres in Shropshire.

Natural England commissioned this study of *Nuphar pumila,* under the Species Recovery Programme to gather information to improve its conservation status at Cole Mere SSSI, Shropshire and to develop and implement a Species Recovery Plan with the aim to maintain a self-sustaining population of N. pumila in England.

The work was commissioned in three parts:

- This report, to review the known ecology of *Nuphar pumila* and the population status at Cole Mere.
- Commissioned report 244 to develop a seed and rhizome propagation protocol.
- Commissioned report 245 to assess the level of genetic variation present in English *N. pumila*; test whether English and Scottish *N. pumila* populations are genetically distinct from each other; and confirm the hybrid nature of samples identified as *N.* × *spenneriana*.

Natural England and others will use the findings to develop a plan to conserve England's only population of least water-lily, and in particular to manage the trees and the margins around Cole Mere.

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Key words - Nuphar pumila, Least Water-lily, Nuphar x spenneriana, Nuphar lutea, Cole Mere SSSI, conservation, strategy, colonisation, ecology, stigmatic disk, monitoring, aerial photography, drone

Further information

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Natural England

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Cover images:

Above: *Nuphar pumila* fruit, showing stigmatic disk Cole Mere 2007 (photo D. Wrench)

Below: *Nuphar pumila*, Cole Mere 2016

Natural England

Development of a conservation plan for Least Water-lily (*Nuphar pumila*) in England

July 2017

Contents

EXECUTIVE SUMMARY

This report provides a synthesis of available information on Least Water-lily (*Nuphar pumila*) including review of options to improve its conservation status at Cole Mere SSSI, Shropshire and through this process present a series of recommendations to enable maintenance of a self-sustaining population of *N. pumila* in England.

Work was commissioned by Natural England under the Species Recovery Programme in three parts:

1. Summarise known ecology of *Nuphar pumila* and population status at Cole Mere (reported here).
2. Seed and rhizome propagation protocol (Peach et al 2017).
3. DNA analysis (Gargiulo et al 2017).

N. pumila is mainly a boreal species of montane or alpine areas, except where it occurs in warm temperate areas in southern China. It occurs from northern Europe east through Siberia and Mongolia to the Russian Far East, Kamchatka, Sakhalin Island, Japan and China. It typically grows on the margins and in sheltered bays of lakes, as well as in pools in marshes and bogs, particularly around raised bogs; it is generally absent from flowing water, except occasionally in oxbows and slow-flowing reaches of rivers.

N. pumila is known from over 100 sites in Scotland, but only from Cole Mere in England, although it formerly occurred in other meres in Shropshire. It was first recorded at Cole Mere in 1854 and was described as “growing abundantly” in early records. When records have specified the location or number of subpopulations, it has been known from only three areas, two bays along the north shore and an area near the boathouse in the south. Throughout the 1990s and 2000s increasing shade around the margin led to a decline in *N. pumila* which was partly reversed by a programme of tree management along the north shore.

It appears that *N. pumila* grows optimally in water up to 2 m deep; it is intolerant of shade (or the secondary effects of shade), probably cannot cope with heavy wave action and may be adversely affected by high turbidity. Taking these factors into account, there is only a very restricted area at Cole Mere where the habitat appears suitable for *N. pumila* and without a long-term strategy for management of the trees around the margin, the population in Cole Mere is unlikely to be self-sustaining or expand beyond the current subpopulations. The only way to establish effective long-term control of this fringing woodland is to grub out or paint stumps and graze the margin but this needs to be done in balance with conservation of other elements of the conservation value of the site. Natural colonisation of other meres is very unlikely and there is little to be gained from an introduction programme until bathymetric data and a long-term strategy for management of trees on each potential receptor site are available.

Data collected to-date are inadequate to derive any measure of population trends. The following options for monitoring were reviewed: documenting the number of subpopulations, recording flowering and seed-set, estimates of the area occupied by floating leaves and counting number of discrete rhizomes. None of these is particularly useful either because of difficulty in collecting replicable data or because of the costs involved. The most effective tool for monitoring *N. pumila* at Cole Mere is likely to involve aerial imagery, and probably use of drones to take aerial photographs, however it would be very valuable to be able to conduct dive-surveys to assess the relationship between the number and extent of rhizomes and the area of floating leaves on the surface.

The distinction between *N. pumila* and *N. lutea* is normally clear and unambiguous, however in spite of the fact that backcrossing and introgression are considered to be rare, identification of *N.* × *spenneriana* is not clear. The biometrics of plants at Cole Mere in 2016 does not provide any support for the suggestion that hybridization is occurring at the site. The results of molecular analysis show that the plants at Cole Mere are *N. pumila* with no evidence of introgression (Gargiulo et al 2017).

1 INTRODUCTION

Least Water-lily (*Nuphar pumila*) is known from over 100 sites in Scotland, but only from Cole Mere in England, although it formerly occurred in other meres in Shropshire. Partly because of the occurrence of *N. pumila* at its only English station, partly because of emphasis on conservation of the "Meres and Mosses" and partly through its use for training in various subjects, Cole Mere has been the subject of extensive research and survey. Much of the available information has been compiled into a number of synthetic reports, but in spite of this there is still little clear information on its current condition or how to reverse perceived declines in its condition. This report is designed to provide a synthesis of available information on *N. pumila,* both from the international and national literature, as well as the "grey" literature, personal observation and data collected as part of this project. This information is pulled together to review options for improvement of the conservation status of *N. pumila* at Cole Mere and through this process present a series of recommendations intended to enable maintenance of a self-sustaining population of *N. pumila* in England.

This report presents information in four main sections:

- Biological data
- Condition of the Cole Mere population
- Reintroduction
- Conclusions

In this report, the following terms have a specific application:

- Population - all plants at a site.
- Subpopulation - one or more stands in an area of a waterbody separated from other stands by a broad area without the same species.
- Stand - one group of plants separated from others by a gap of more than 20 m.

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2 ECOLOGY AND IDENTIFICATION OF *NUPHAR* SPECIES IN THE UK

2.1 Introduction

Four *Nuphar* taxa have been reported occurring in the wild in the UK (Preston and Croft): *N. advena*, *N. lutea*, *N. pumila* and the hybrid between the last two - *N.* × *spenneriana*. In recent years herbarium specimens identified as *Nuphar advena* have been reviewed (M. Spencer pers. comm.) and sites from which it has been reported have been visited it but has not been possible to confirm any record. *N. advena* should therefore not be considered a member of the British flora unless some confirmation can be obtained. The other three taxa are described in detail below.

2.2 *Nuphar pumila*

2.2.1 Morphology

Rhizomes stout 1–3 cm in diameter. Leaves submersed and floating; petioles compressed to slightly keeled, 1–5 mm in diameter; floating blades green to purple, broadly elliptic to broadly ovate, 5–15.5(–17) × (4–)5.5–12.5 cm, 1–1.7 times as long as wide, 10–21 lateral veins per side, sinus 3–6.3 cm, ca. 0.4 times the length of the blade, lobes approximate to divergent, blades glabrous to densely pubescent below. Flowers 1.3–3.5(–6) cm in diameter; peduncles 2.5–5.5 mm in diameter, glabrous or occasionally pubescent; sepals mostly 5(–7), yellow, greenish toward base, obovate, apices rounded; petals thin, spathulate, yellow-orange; anthers 1–2.5 (–6) mm, yellow, 2–5 times shorter than the filaments. Fruits green, ovoid to urceolate, 1.5–3(–4.5) × 0.9–2 cm, 1.1– 2.3 times as long as wide, fruit wall smooth; neck stout, 2.5–4(–5) mm in diameter, slightly furrowed, usually 0.25 times as wide as the ovary; stigmatic disk green, sometimes yellow to reddened, deeply lobed to dentate, 4–7.5(–9.5) mm in diameter, 0.3–0.4 times as wide as the ovary, rays 8–14, linear, terminating at the disk margin. Seeds 17–90 per fruit, greenish brown to brown, ovate, 3–4 mm in length (Padgett 2007).

Figure 2.1 Three submerged (left, below and right) and one floating leaf of *Nuphar pumila*, Scotland 2010

Figure 2.2 Stigmatic disks of *Nuphar pumila*, Norrbotten, Sweden 2012

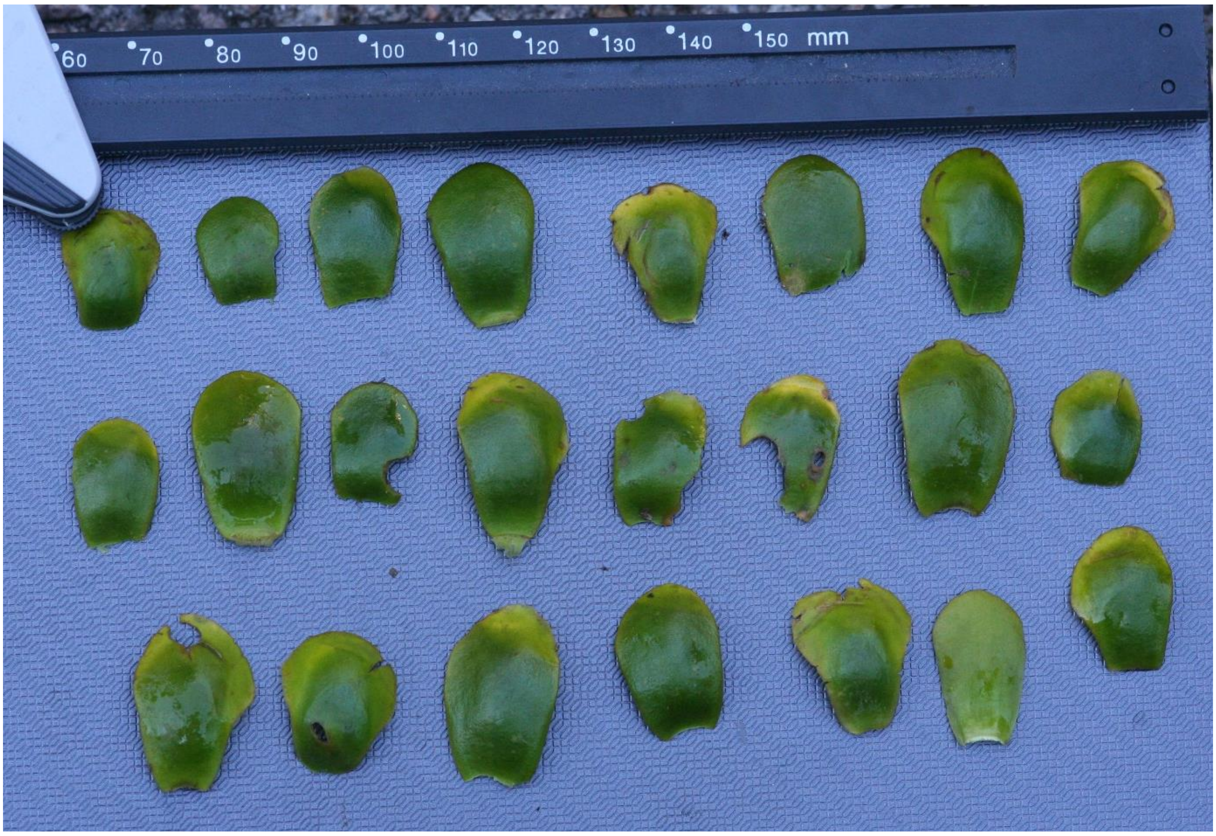

Figure 2.3 Sepals of *Nuphar pumila*, Cole Mere, 2016

2.2.2 Distribution

N. pumila is mainly a boreal species of montane or alpine areas, except where it occurs in warm temperate areas in southern China. It occurs from northern Europe east through Siberia and Mongolia to the Russian Far East, Kamchatka, Sakhalin Island, Japan and China. In Europe it occurs throughout Scandinavia and northern parts of the United Kingdom, in the southern part of its range it is restricted to mountains, occurring south to the Balkans (Padgett 2007, Akhani 2014). In the UK it is generally a lowland species, occurring from 0-300 m altitude (Preston and Croft 1997) but in Switzerland it is typical of montane(-subalpine) areas 495-1300 m altitude (to 1700 m in Austria) (Info Flora 2016). In North America, *N. pumila* is replaced by *N. microphylla* (Padgett 2007).

2.2.3 Ecology

N. pumila typically grows on the margins and in sheltered bays of lakes, as well as in pools in marshes and bogs, particularly around raised bogs; it is generally absent from flowing water, except occasionally in oxbows and slow-flowing reaches of rivers (Stewart, Pearman and Preston 1994, Preston and Croft 1997, Preston, Pearman and Dines 2002, Padgett 2007, Info Flora 2016). It appears to be restricted to water 0.5-3.5 m deep (Preston and Croft 1997, Info Flora 2016) but does not flower in water over 2 m deep (Koslowski 2001) where it may be considered to be in sub-optimal condition. It usually occurs in oligotrophic or more frequently mesotrophic sites some of which receive base-rich drainage water (Preston and Croft 1997, Preston, Pearman and Dines 2002) which are poor in Ca^{2+} and is confined to organic substrates (Skańkowski and Klosowski 1999), although it is described as occasionally occurring in slightly eutrophic fish ponds in Switzerland (Info Flora 2016) but in cold and slightly acid water in the canton of Fribourg (Koslowski 2001). In spring the plant forms submerged, almost transparent leaves (see Figure 2.1), but as soon as the temperature of the water starts to exceed 110° C, around mid-May, floating leaves start to develop (Info Flora 2016). Between late August and late September, the floating leaves degrade, but the submerged leaves may overwinter. It typically grows rooted in organic peat, mud or silt (Stewart, Pearman and Preston 1994, Preston and Croft 1997, Skańkowski and Klosowski 1999, Info Flora 2016) at Cole Mere, the rhizome appears to be more or less buried in very soft silt.

N. pumila often occurs as isolated stands and frequently only one stand in smaller water bodies. It is the characteristic species of the Nupharetum pumilae Oberd. 1957 22.4311 “vegetation of lakes and ponds with unintensive management, shallow oligotrophic to mesotrophic water of montane or sub-montane zones” (Ferrez *et al*. 2011) but will occur in the Potametea (Kraska *et al*. 2006) and the Nymphaeon albae (Info Flora 2016). It typically occurs alone or with species such as *Nuphar lutea, Nymphaea alba*, *Persicaria amphibia* and *Potamogeton natans* (Kraska et al. 2006).

Figure 2.4 Floating mats of rhizomes among floating leaves of *Nuphar pumila*, Cole Mere, 2016 (photo J. Peach)

Figure 2.5 Bathymetric map of Cole mere showing 1 m depth contours, blue indicates depths of 0-1 m and red 1-2 m, green shading indicates the current extent of woodland, black polygons indicate current populations of N. pumila and the bright green polygon in the south indicates the population near the boat house which has disappeared (base map from Dempster and Gasca 2015).

N. pumila produces only a small amount of nectar (Info Flora 2016) however experiments have shown that the flowers are not automatically self-pollinated and no fruit develop in *N. pumila* flowers from which all insect visitors were excluded (Padgett 2007). They are mainly pollinated by bees, bumblebees and hover-flies which may effect either self- or cross-pollination (Stace, Preston and Pearman 2015). Most populations are fertile, although some show reduced fertility possibly due to introgression with *N. lutea* (Preston and Croft 1997), although this is not supported by molecular analysis (Gargiulo, 2017) and after fertilisation, the peduncles recurve such that the fruit ripens under water, the carpels float allowing seed to drop to the bed (Info Flora 2016). Little is known of germination and seedlings have not been seen in the wild (Preston and Croft 1997). The seeds lack morphological adaptations for animal dispersal, they are killed by desiccation and are completely digested when eaten by birds or fish, dispersal of seeds must therefore mainly be by water movement. Most reproduction is likely to be mainly by fragmentation and rhizome growth, including at Cole Mere where it is clear that no new populations of *N. pumila* have developed for at least 20 years (A.J. Lockton pers. comm.). It is of note that on both occasions that the Cole Mere population was visited during the growing season in 2016, rhizome fragments were found floating on the surface and this may be a major dispersal strategy but is evidently not very effective in establishing other populations at Cole Mere. This could be either because conditions elsewhere in the mere are unsuitable for sustaining freshly rooted rhizomes or it is difficult for free floating rhizomes to physically take root again in the first place.

At Cole Mere throughout the 1990s and 2000s it is thought that increasing shade around the margin led to a decline in *N. pumila*. The first indication of this was the loss of the population in the south near the boat house (Walker 2001) and by 2003 the only remaining subpopulation visible was in the western bay along the north shore (S.J. Whild in Shropshire Botanical Records) (see Figure 2.5). During this period the extent covered by floating leaves in both of the northern bays also declined (Lockton and Whild 2006). However by 2006 it had reappeared in both bays along the north shore following work to clear rhododendrons overhanging the margin (Whild and Lockton 2006). Whilst this cannot be tested, it appears likely that the rhizomes survived in both bays but produced fewer floating leaves when shaded. It is also possible, however, that it is not the shading alone which caused the decline but a secondary aspect of the shading such as leaf litter deposition. It has been shown that even a six millimetre thick layer of leaves or silt can adversely affect germination of seeds of some aquatic and mud plants (Baskin and Baskin 1998), while Bonis, Lepart and Grillas (1995) showed that there is almost no germination from a mud-plant seed bank when seeds are situated more than 2 cm below the surface of the sediment. The accumulation of decaying plant material and possibly even anoxic conditions which may develop as a consequence of the build-up of leaf litter may suppress germination (Dring and Frost 1971). It is therefore possible that leaf deposition could have an adverse effect on the regrowth of leaves from the buried rhizome of a species such as *N. pumila* but this remains to be confirmed.

It is also possible that the generally very high turbidity of Cole Mere could adversely affect the vitality of *N. pumila* plants. For example, although there is no evidence to support the hypothesis, it seems reasonable to assume that the submerged leaves of *Nuphar* species may have a different role to the floating leaves. Particularly if, as appears to be the case, they persist for longer than the floating leaves and could actually be perennial, it is possible that the submerged leaves continue to photosynthesise after the floating leaves have degraded as well as possibly before the floating leave develop. If this is the case, then low light conditions which could be caused by factors such as tree shade, leaf litter deposition or water turbidity, may compromise the ability of these submerged leaves to photosynthesise which could render conditions at Cole Mere sub-optimal, increasing the impact of other adverse effects which would otherwise be insignificant. *N. pumila* is also likely to have a relatively low tolerance of wave action and this may be why it is typically restricted to sheltered areas.

Figure 2.5 shows that there is only a very restricted area at Cole Mere where the water depth is suitable for *N. pumila* and that the largest area with a suitable depth coincides with heavily wooded margins except along the eastern shore and near the boat house which are subject to wave action and the activities of waterfowl. Throughout the history of Cole Mere and work toward its conservation, there has been speculation about the influence of water chemistry, particularly nutrients, on the vegetation and particularly on *N. pumila*. In fact, the bathymetry and shading provide a credible explanation for the distribution and abundance of *N. pumila* at Cole Mere such that there is no need to invoke nutrients as a cause of low population levels. However, it is possible that one reason for the wide distribution of *N. lutea*, compared to that of *N. pumila* is the ability of the former to tolerate a much wider range of conditions, from highly oligotrophic to quite strongly eutrophic and it is feasible that the nutrient balance of the mere has an influence over the vegetation. Whilst probably not critical for conservation of *N. pumila* at Cole Mere, investigation of the chemical tolerance of *N. pumila*, with particular reference to nitrate and phosphate levels, through *ex situ* studies, could help to inform conservation of the species and could be carried out through a PhD.

2.2.4 Threats

In the UK, *N. pumila* populations appear to be more or less stable (Preston, Pearman and Dines 2002) and there is no evidence of any significant threat to UK populations. In continental Europe it is considered to be threatened by eutrophication (agriculture, fertilisation and liming for fish-farming), leisure activities (navigation, bathing, fishing, sail-boarding), pollution, drainage, modification of the hydrological regime, seral and hydrological succession and collection for horticulture (Info Flora 2016).

2.3 *Nuphar lutea*

2.3.1 Morphology

Rhizomes stout, 3–8(–15) cm in diameter. Leaves submersed and floating; petioles trigonous, 3–10 mm in diameter; floating blades green, broadly elliptical to ovate, 16–30 × 11.5–22.1 cm, 1.1–1.5 times as long as wide, 16–29 lateral veins per side, sinus 5–11 cm, ca. ⅓ the length of the blade, lobes approximate to overlapping, blade glabrous to pubescent below. Flowers 3–4.5(–6.5) cm in diameter; peduncles 4–10 mm in diameter, glabrous to occasionally pubescent; sepals mostly 5(6), yellow, greenish toward base, broadly obovate, apices rounded; petals thin, truncate, rounded, to spathulate, usually yellow (reddened); anthers 4–7 mm, yellow, 1–2 times shorter than the filaments. Fruits green, urceolate, 2.6–4.5 × 1.9–3.4 cm, 1.0–1.4 times as long as wide, fruit wall smooth; neck prominent, narrow, 3–9 mm in diameter, smooth to slightly furrowed, usually 0.2 times as wide as the ovary; stigmatic disk green (sometimes yellow), essentially entire, 7–13 mm in diameter, 0.34 times as wide as the ovary, rays 11–21, linear to ovate, terminating at or within 1 mm of margin. Seeds numerous, up to 400 per fruit, olive green, ovoid, 3.5–5 × ca. 3.5 mm. (Padgett 2007).

Figure 2.6 Underside of floating leaf of *Nuphar lutea*, River Ouse, Yorkshire, 2009, with petiole cross-section to the left

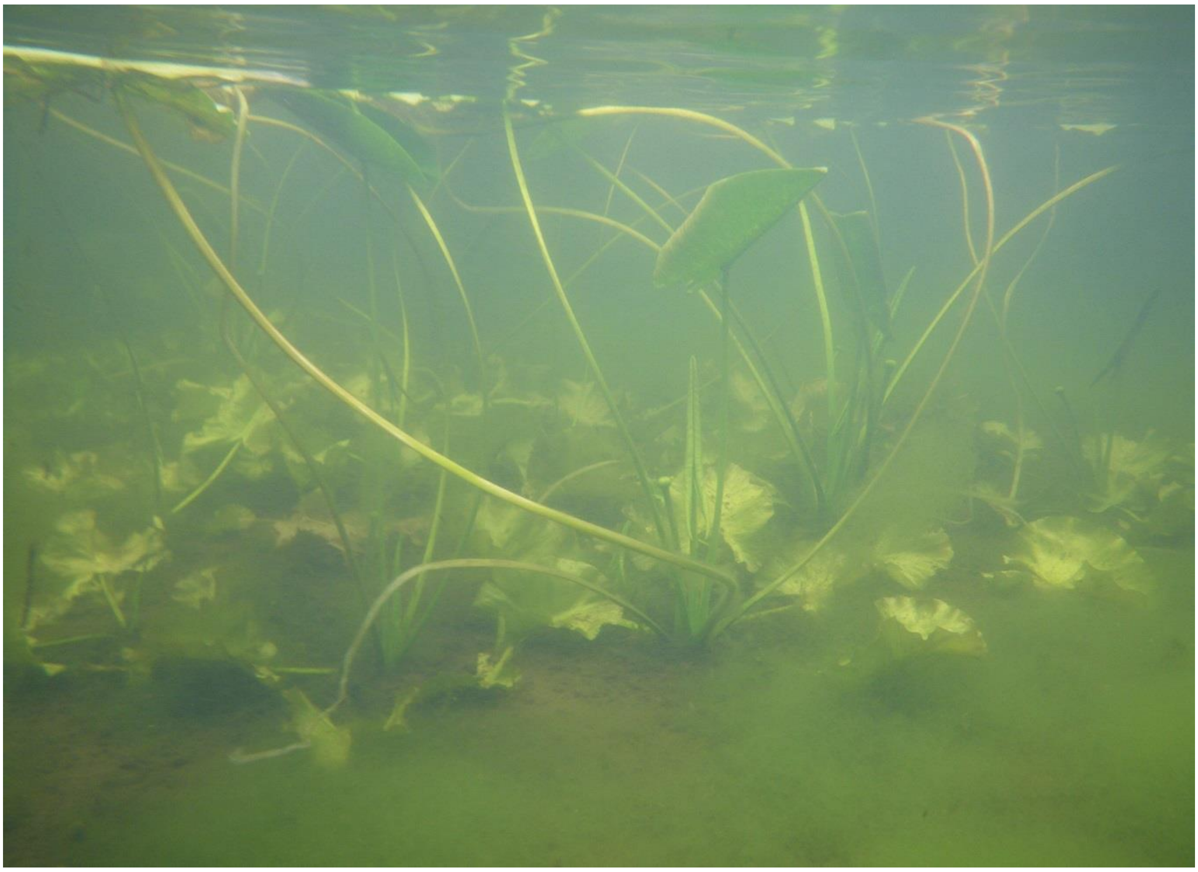

Figure 2.7 Growth form of *Nuphar lutea*, Elterwater, Cumbria 2010, showing submerged and floating leaves

Figure 2.8 Stigmatic disks of *Nuphar lutea*, Norrbotten, Sweden 2012

2.3.2 Distribution

N. lutea occurs from Europe south to the Mediterranean and east through the Middle East, the Caucasus, Siberia and Kazakhstan to China. It occurs more or less throughout Europe, except for the Balearic Islands, Corsica, and Crete, and is known only from a few sites in Algeria (Padgett 2007, Akhani 2014).

2.3.3 Ecology

Figure 2.9 Sepals of *Nuphar lutea*, Norrbotten, Sweden 2012

N. lutea grows in mildly acidic or basic, mesotrophic or eutrophic water of lakes, slow-flowing rivers, canals and large ditches from 0-510 m altitude (Preston and Croft 1997, Preston, Pearman and Dines 2002). It is normally found in open water at depths of 0.5-2.5 m but it has been recorded as deep as 3.6 m. *N. lutea* is often found over mud or silt and rarely over peat, in rivers it is particularly characteristic of clay substrates (Preston and Croft 1997). Lakes in the north and west of the UK supporting *N. lutea* are typically species-poor, with only a few species such as *Elodea canadensis*, *Equisetum fluviatile*, *Juncus bulbosus*, *Littorella uniflora*, *Nymphaea alba* and *Potamogeton obtusifolius* (Preston and Croft 1997). In rivers it can occur with a wide range of species, from *Apium inundatum*, *Callitriche brutia* subsp. *hamulata*, *Luronium natans*, *Myriophyllum alterniflorum*, *Potamogeton polygonifolius* and *Ranunculus penicillatus* subsp. *penicillatus* in oligotrophic western rivers to *Callitriche obtusangula*, *Lemna minor*, *Potamogeton berchtoldii*, *P. lucens*, *P. natans*, *Schoenoplectus lacustris*, *Sparganium emersum* and *S. erectum* in mesotrophic to eutrophic lowland rivers and canals. *N. lutea* is tolerant of mechanical disturbance and can occur along the edge of rivers and canals which carry considerable boat traffic, although in very disturbed sites it persists as plants with submerged leaves which rarely produce floating leaves or flowers (Preston and Croft 1997).

Figure 2.10 Ripe carpels of *Nuphar lutea* containing seeds and seeds on the shoreline of a lake, Scotland 2010

N. lutea overwinters as a rhizome, producing translucent submerged leaves in early spring and coriaceous floating leaves in April and May, (Padgett 2007) at Cole Mere, the floating leaves persisted at least into late September in 2016. As is the case with *N. pumila*, *N. lutea* flowers are mainly pollinated by bees, bumblebees and hover-flies and experimental evidence showed that no seeds ripen in fruit from which all insect visitors were excluded (Padgett 2007). The fruit ripens above the water and the seeds are embedded in the spongy tissue of the carpel (Figure 2.10) which normally sink within a day or its release. The seeds lack morphological adaptations for animal dispersal, they are killed by desiccation and completely digested when eaten by birds or fish. The main chance of dispersal must be by water movement and long-distance dispersal must be a rare event (Preston and Croft 1997).

2.4 *Nuphar × spenneriana*

2.4.1 Morphology

Rhizomes stout 1.8–2.9 cm in diameter. Leaves submersed and floating; petioles dorsally compressed, 2–6 mm in diameter; floating blades green, broadly elliptical to ovate, 9.2–20.5 × 6.1–15.0 cm, 1.1–1.5 times as long as wide, 11–19 lateral veins per side, sinus 3.4– 7.5 cm, ca. ⅓ the length of the blade, lobes approximate to barely overlapping, blades usually glabrous below. Flowers 2–3 cm in diameter; peduncles 4–6 mm in diameter, glabrous to occasionally pubescent; sepals mostly 5, yellow, greenish toward base, obovate, apices rounded; petals thin, rounded to spathulate, usually yellow; anthers 2.5–4.5 mm, yellow, longer than the filaments. Fruits green, urceolate and often recurved, commonly emaciated, 1.7–3.0 ×1.1–2.0 cm, 1.1–2.2 times as long as wide, fruit wall smooth; neck prominent, narrow, 3–4 mm in diameter, smooth to slightly furrowed, usually 0.25 times as wide as the ovary; stigmatic disk yellow, crenate, 5–7 mm in diameter, ca. 0.4 times as wide as the ovary, rays 9–15, linear, terminating at or within 1 mm of margin. Seeds usually few, 6–40 per fruit, 2–5 mm long. (Padgett 2007).

2.4.2 Distribution

N. × *spenneriana* is frequent in Norway, Sweden and Finland, it occurs south to central Europe and east to south central Siberia and Russia (Padgett 2007, Stace, Preston and Pearman 2015). It generally occurs in areas of overlap between the two parent species (Heslop-Harrison 1975), both in terms of latitude and in the alps, altitude (Koslowski 2001). Isolated populations in England are understood to represent relic populations from early post-glacial times when the parents coexisted (Heslop-Harrison 1975).

2.4.3 Ecology

N. × *spenneriana* occurs in water up to c 2 m deep over both peat and mineral soil, in oligotrophic and mesotrophic lakes, pools, the quiet backwaters and slow-flowing reaches of rivers and in streams up to 476 m altitude, with or in the absence one or both parents (Heslop-Harrison 1953, Padgett 2007, Stace, Preston and Pearman 2015). It is capable of a limited degree of vegetative spread by the growth of its rhizomes and as appears to be the case with *N. pumila*, dispersal within water bodies may occur through movement of floating rhizome fragments.

Figure 2.11 Mixed stand of *Nymphaea alba* var. *alba* with *Nuphar* × *spenneriana* and probably *N. pumila*, Loch Uvie 2016

Figure 2.12 Stigmatic disks identified as mixed *Nuphar* × *spenneriana* and *N. pumila*, Loch Uvie 2016, the scale is in millimetres

Fertility is reported by Heslop-Harrison (1953) to be markedly reduced among most *N.* × *spenneriana* populations as measured by pollen stainability and seed germination, where 85% of pollen grains and 80% of ovules are sterile, although pollen fertility has been reported as high as 71% (Caspary 1869). However, plants referable to this taxon are capable of producing viable seed (Heslop-Harrison 1953) and in cultivation the seeds appear to germinate more rapidly than those of the parent (Preston and Croft 1997, Padgett 2007) but seedlings have not been found in the wild (Stace, Preston and Pearman 2015). Backcrossing is theoretically possible although very rarely encountered in Britain but in continental Europe it seems to occur more frequently, giving rise to more variable populations (Stace, Preston and Pearman 2015).

Figure 2.13 Stigmatic disks of presumed *Nuphar* × *spenneriana*, Norrbotten, Sweden 2012

Figure 2.14 Sepals of presumed *Nuphar* × *spenneriana*, Norrbotten, Sweden 2012

2.5 Identification

The distinction between *N. pumila* and *N. lutea* is normally clear and unambiguous, however in spite of the fact that backcrossing and introgression are considered to be rare, identification of *N.* × *spenneriana* is not clear. Stace (2010) provides the following key:

1	Leaves with 23-28 lateral veins on each side; stigmatic disk 10-15 mm across, circular or slightly crenate at margins, with 9-24 rays; flowers 3-6 cm across	*N. lutea*
	Leaves with 11-22 lateral veins on each side; stigmatic disk 6-11 mm across, crenate to lobed at margin, with 7-14 rays; flowers 1.5-4 cm across	2
2	Leaves with 15-22 lateral veins on each side; stigmatic disk 7.5-11 mm across, crenate at margin with 7-14 rays; stamens 60-100; pollen <25% fertile	*N.× spenneriana*
	Leaves with 11-18 lateral veins on each side; stigmatic disk 6-8.5 mm across, distinctly lobed at margin, with 7-12 rays; stamens 37-65; pollen >90% fertile	*N. pumila*

This suggests that there is no overlap in the number of lateral veins in the floating leaves between *N. lutea* and *N.× spenneriana*, which disagrees with data presented by Padgett (2007) (see Table 2.1 below). It is further complicated by the lack of precision as to which veins are actually counted; *Nuphar* species have both primary and secondary veins (Figure 2.15) and the assumption is that the figures given refer to the primary veins, but this is not clear. It is of note that the figures given by Stace (2010) disagree fairly widely with those given by Padgett (2007) and there is no obvious way of know which may be considered reliable.

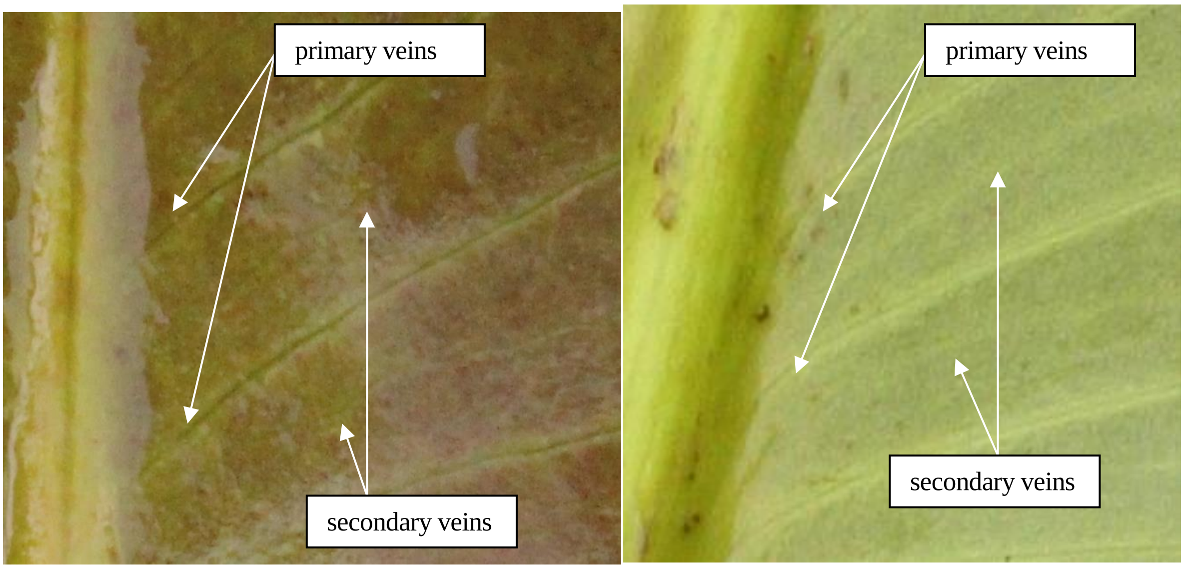

Figure 2.15 Venation of *Nuphar pumila* (left) and *Nuphar* × *spenneriana* leaves showing venation

Table 2.1 presents comparative information from the botanical description by Padgett (2007) for the three taxa. Whilst *N. pumila* ad *N. lutea* are clearly separable in many ways, including petiole cross-section, leaf and anther length, stigmatic disk margin and number of seeds per fruit, separation of *N.* × *spenneriana* from either of its parents is unclear. A combination of longer and wider leaves, longer anthers and very few seeds per fruit could serve to distinguish *N.* × *spenneriana* from *N. pumila*, while a combination of narrower and shorter leaves with fewer lateral veins, lower flower diameter, shorter anthers, crenate stigmatic disk margin and more seeds per fruit should serve to distinguish *N.* × *spenneriana* from *N. lutea*. However there is some degree of overlap in all characters and identification will not be straightforward.

Table 2.1 Morphological and descriptive data from Padgett (2007).

	N. pumila	*N.* × *spenneriana*	*N. lutea*
Rhizome diameter	1-3 cm	1.8-2.9 cm	3–8 (–15) cm
Petiole			
shape	compressed to slightly keeled	dorsally compressed	trigonous
diameter	1-5 mm	2-6 mm	3–10 mm
Floating leaves			
colour	green to purple	green	green
outline	broadly elliptic to broadly ovate	broadly elliptical to ovate	broadly elliptical to ovate
length	5–15.5 (–17) cm	9.2–20.5 cm	16–30 cm
width	(4–) 5.5–12.5 cm	6.1–15.0 cm	11.5–22.1 cm
length : width ratio	1–1.7	1.1–1.5	1.1–1.5
lateral veins each side	10-21	11-19	16-29
sinus depth	3-6.3 cm	3.4–7.5 cm	5–11 cm
sinus depth : blade	0.4	ca. ⅓	ca. ⅓
sinus shape	lobes approximate to divergent	lobes approximate to barely overlapping	lobes approximate to overlapping
pubescence	glabrous to densely pubescent below	blades usually glabrous below	glabrous to pubescent below
Flower diameter	1.3–3.5 (–6) cm	2–3 cm	3–4.5 (–6.5) cm

Peduncle diameter	2.5–5.5 mm	4–6 mm	4–10 mm
Peduncle pubescence	glabrous or occasionally pubescent	glabrous to occasionally pubescent	glabrous to occasionally pubescent
Sepal number	5 (-7)	mostly 5	5 (-6)
Sepal colour	yellow, greenish toward base	yellow, greenish toward base	mostly yellow, greenish toward base
Sepal shape	obovate, apices rounded	obovate, apices rounded	broadly obovate, apices rounded
Petal shape	thin, spathulate	thin, rounded to spathulate	petals thin, truncate, rounded, to spathulate
Petal colour	yellow-orange	usually yellow	usually yellow (red)
Anther length	1–2.5 (–6) mm	2.5–4.5 mm	4-7 mm
Anther colour	yellow	yellow	yellow
Filament: anther length	2-5 x	shorter	1-2 x
Fruit			
colour	green	green	green
shape	ovoid to urceolate	urceolate, often recurved, commonly emaciated	urceolate
length	1.5–3 (–4.5) cm	1.7–3.0 cm	2.6–4.5 cm
width	0.9–2 cm	1.1–2.0 cm	1.9–3.4 cm
length : width	1.1-2.3 x	1.1–2.2	1.0–1.4 x
wall texture	smooth	smooth	smooth
neck diameter	stout 2.5–4 (–5) mm	narrow, 3–4 mm	narrow 3–9 mm
texture	slightly furrowed	smooth to slightly furrowed	smooth to slightly furrowed
width relative to ovary	0.25 x	usually 0.35 x	0.2 x
Stigmatic disk			
colour	green, sometimes yellow to red	yellow	green (sometimes yellow)
shape	deeply lobed to dentate	crenate	entire
diameter	4–7.5 (–9.5) mm	5-7 mm	7-13 mm
width relative to ovary	0.3–0.4 x	ca. 0.4 x	0.34 x
number of rays	8-14	9-15	11-21
termination	at the margin	at or within 1 mm of margin	at or within 1 mm of margin
Seeds			
number per fruit	17–90	6-40	up to 400
colour	greenish brown to brown	?	olive green
shape	ovate	?	ovoid
length	3–4 mm	2-5 mm	3.5–5 mm

In fact, it is likely that the best characters for separating *Nuphar pumila* from *N.* × *spenneriana* are the occurrence of at least some leaves in any population which fall above the ranges given for *N. pumila*; a measure of fertility, although fertility of aquatic plants can be affected by factors such as temporary submergence of developing flowers and should be used with caution; and the outline of the stigmatic disk. Many *N. lutea* populations in areas where the possibility of hybridization with *N. pumila* is vanishingly small, include small leaves which simply appear to be immature or on immature plants. It is probably best, therefore to treat the occurrence of small leaves in populations of *N. lutea* with some caution. *N.* × *spenneriana* is probably best separated from *N. lutea* by a combination of small fruit with clearly crenate stigmatic disk and very small numbers of seed in the fruit.

Neither the biometrics nor molecular analysis of plants at Cole Mere in 2016 provide any support for the suggestion that hybridization is occurring at the site (Table 2.2). However the stigmatic disks are much less conclusive (Figure 2.16). Padgett (2007) notes “emaciated” fruit only in *N.* × *spenneriana* but such fruit have been found in *N. pumila* at Cole Mere.

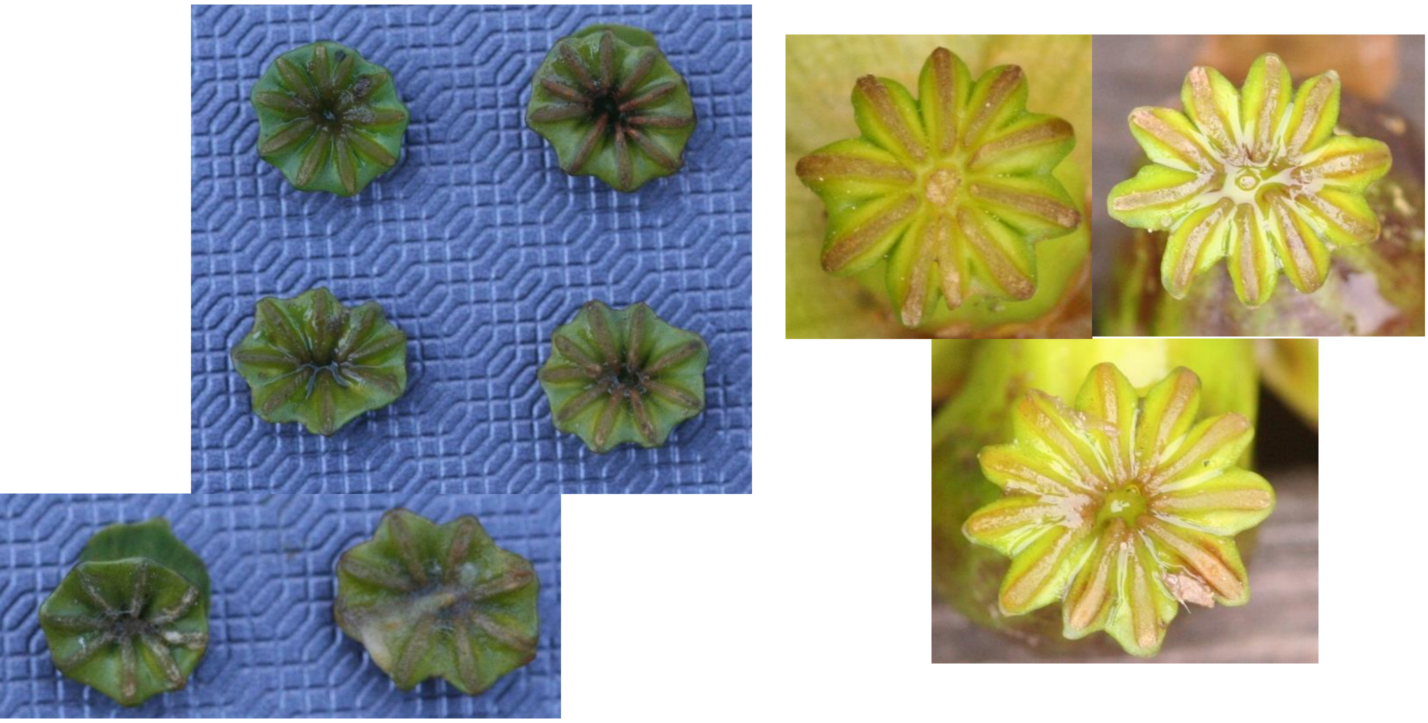

Figure 2.16 Stigmatic disks, "*Nuphar pumila*" from Cole Mere (six on the left), *N. pumila* from Norrbotten, Sweden (3 right)

Table 2.2 Morphological and descriptive data from material collected for molecular analysis

Nuphar pumila			
Location	**length (mm)**	**width (mm)**	**No. veins on each side**
Rannoch Moor	86.5	71.5	16
Rannoch Moor	85	69	14
Rannoch Moor	85.5	69.5	14
Rannoch Moor	83.5	72.5	15
Rannoch Moor	57	52	15
Little Rogart Loch	82.5	62.5	13
Little Rogart Loch	98.5	77.5	15
Little Rogart Loch	113.5	87	19
Little Rogart Loch	94.5	75	13
Cole Mere	117.5	91	17
Cole Mere	109	83.5	14
Cole Mere	93	80	15
Cole Mere	117	91.5	16
Cole Mere	118	95	20
Cole Mere	124	100	17
Loch Uvie	110	88	16
Loch Uvie	125	103.5	18
Loch Uvie	131	100	19
Loch Uvie	67	50	9
Loch Uvie	97.5	78	14
Range	**57-131**	**50-103.5**	**9-20**

Nuphar lutea			
Location	**length (mm)**	**width (mm)**	**No. veins on each side**

Cole Mere	240	242	34
Cole Mere	300	265	38
Cole Mere	298	237	36
Cole Mere	335	265	35
Cole Mere	325	266	32
Kirrieroch Loch	190	159	21
Kirrieroch Loch	143	110	19
Range	**143-335**	**110-226**	**19-38**

3 CURRENT CONDITION AND MONITORING AT COLE MERE

3.1 Introduction

Cole Mere is one of the largest of the Shropshire meres, it is fringed by woodland apart from the eastern margin and a short section at the north-western end, although formerly it had grazed margins and reed bed with no woodland (Lockton and Whild 2006). It is classed as hyper-eutrophic and appears typical of the Midlands Meres in that it experiences cyanobacterial blooms, a common feature in both stratified and stratified water, supported by an internal source of nutrients. It is situated within a natural hollow and there is a small inflow stream in the north west corner, however the major source of water is groundwater with flow entering the mere from the glacial sand and gravel aquifer during high water level conditions. Cole Mere lies adjacent to the Shropshire Union Canal, and a spillway directs canal overflow water into the mere. Estimates are available for the quantity of water this inflow provides to the mere and there are water quality data for 2015-2016 which will enable some estimation of the potential influence of this inflow on the water quality of Cole Mere (Dempster and Gasca 2015). Water in the canal is likely to have different chemistry to that of Cole Mere, owing to its origin in the Welsh mountains and the influence of boat traffic stirring up sediment from the canal bed. There is an outflow on the eastern margin of the mere (ECUS 2001, Lockton and Whild 2006, Burgess, Goldsmith and Goodrich 2014, Dempster and Gasca 2015).

Table 3.1 Selected historical records of *N. pumila* at Cole Mere which include information on abundance (from Lockton and Whild 2006)

1970	Sinker, C.A.	Two bays in north-east shore
1979	M.J. Wigginton	Three stands mapped (Wigginton 1980)
1985	Walker, C.	Large patch, SE end of Cole Mere.
1987	M.J. Wigginton	Three stands mapped (Wigginton 1989)
1990	Walker, C.	Four separate colonies, NE and SE shores of Cole Mere. At several stations NE shore, also near boathouse landing stage of SE shore.
2001	Hogarth, C. and Walker, C.	Distribution of water plants is similar to that in previous surveys. A significant difference, however, is the apparent loss of the patch of *Nuphar pumila* that used to occur in the south-east corner of the mere. A few years ago this was quite big, and a good, easily accessible place to see the species. Its apparent loss may be a result of shading by the alders which occupy the margin at this point (Walker 2001)
2003	Whild, S.J.	Just one patch in a bay on the north-west side of the mere. It has disappeared from all its other locations.
2005	Lockton, A.J.	Three small patches close to the north shore of the mere, between SJ43433349 and SJ43393349 [these grid references frame the eastern of the two bays along the northern shore RVL]
2006	Lockton, A.J.	Thriving along the north shore in two places following clearance of rhododendrons overhanging the water.
2011	Lockton, A.J.	Two patches on the north shore, both expanding following tree clearance in 2005-2006
2014	Meres and mosses volunteers	Patch 1 Small area under willow, 2.5 x 1 m, approx 20m north east of patch 2; Patch 2 larger area approx 20m from patch 1, 18.6 x 11 m, 52.895909, -2.842667; Patch 3 large patch west top end of lake, 28.4 x 13.20 m, 52.895917, -2.84925293

Cole Mere is alkaline (Mean pH = 7.96), the mean annual total phosphorus (2007-2009) is 82 µgl-1, nitrate concentrations are relatively low (mean TN = 1.04 mgl-1 and mean TON =0.18 mgl-1), mean chlorophyll *a* concentrations are moderate (22.27 µgl-1) and rather variable throughout the year (range = 3 – 65 µgl-1) (Dempster and Gasca 2015) The frequent high algal turbidity appears to inhibit plant growth in open water and although dissolved oxygen concentrations are high in the surface waters, they decline sharply below approximately 6 m, indicating anoxia of the bottom waters. Water samples have shown high levels of soluble reactive and total phosphorus, lake bed coring results from nearby Crose Mere and Hatch Mere by Liverpool University show a rise in phosphate levels in the sediment consistent with recent anthropogenic influences and this is likely to be the case at Cole Mere. Analysis of the water quality has shown significant increases in phosphorus in the summer and ammonium concentrations in the winter, suggesting that internal release from the sediments could be a significant source of P and external sources of N, along with groundwater movement (Burgess, Goldsmith and Goodrich 2014, Dempster and Gasca 2015) or surface water. The high nutrient levels in Cole Mere have been attributed to a number of factors, from groundwater and surface water inputs to the occurrence of large numbers of wildfowl, particularly non-native Anatidae such as Canada (*Branta* *canadensis*) and greylag (*Anser anser*) geese. It is highly likely that reduction of the number of non-native wildfowl using the mere would reduce nutrient enrichment or at least slow down the rate of eutrophication.

3.2 History and current condition of *N. pumila* at Cole Mere

N. pumila was first recorded at Cole Mere in 1854 and was described as "growing abundantly" in early records (e.g. T.A. Cox 1855 in The Phytologist Vol. 1 cited by Lockton and Whild 2006). It has been recorded sporadically since then until the 1980s when recording became more regular. It has been recorded from a total of three locations at Cole Mere; one near the boat house and two in bays along the north shore. No records prior to 2000 provide precise information on the location and extent of stands (although sources do indicate the distribution of stands on maps) and subsequent records only give a total assessment of the area covered by floating leaves in each subpopulation (e.g. Burgess, Goldsmith and Goodrich 2014). Table 3.1 shows records which include some measure of abundance. It is of note that *N. pumila* was only recorded from two bays along the north shore in 1970. Whilst this does not rule out the possibility that the subpopulation near the boat house was present, it seem unlikely that this subpopulation would have been missed by the recorder, C.A. Sinker.

Figure 3.1 *N. pumila* in the western bay, Cole Mere, August 2016, below with red lines illustrating one interpretation of the number of stands

It is interesting to consider the distribution of plants at Cole Mere:

- The prevailing wind is from the south-west and the two remaining subpopulations are in the north of the mere, and it is feasible that this is where rhizome fragments carried by wind action on the lake would be deposited. Rhizome fragments from these two subpopulations will almost certainly not result in the establishment of new subpopulations and are unlikely to enable these populations to persist, rather they are likely to be deposited on the strandline.
- The southern subpopulation was close to the point where any rhizome fragments carried by boats moored or stored in the boat Club area might be expected to be dropped. Rhizome fragments arising from this subpopulation are likely to be carried across the mere.
- The only areas of the Mere less than 2 m depth which have not been known to support *N. pumila* are along the eastern shore which is subject to strong wave action and the effects of wildfowl and along eastern parts of the northern shore which are currently shaded.

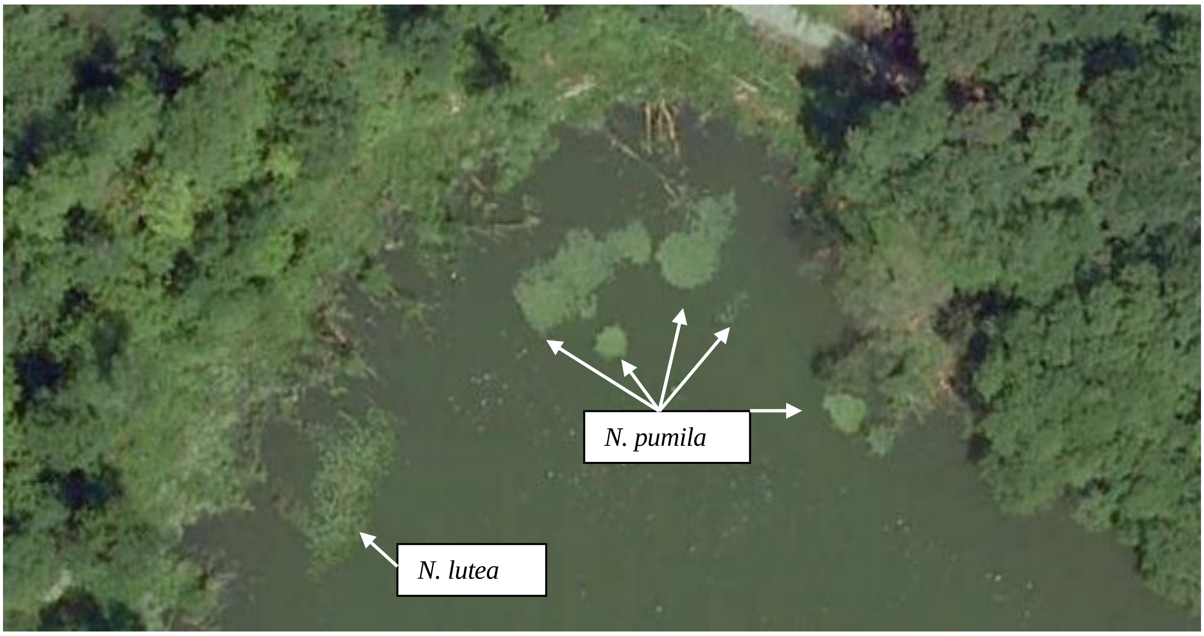

Figure 3.2 Google Earth image of eastern bay, dated 24th June 2009

Figure 3.3 Google Earth image of western bay, dated 24th June 2009, all floating leaves are *N. pumila*

It will never be possible to establish for certain whether the southern subpopulation established as a result of human intervention, although the lack of mention of this subpopulation before 1970 and its location make the question a reasonable one. The decline in the number of subpopulations with floating leaves raised concern about the condition of the subpopulations, subsequent cutting of *Rhododendron ponticum* and some of the fringing woodland led to an increase in the area covered by *N. pumila* leaves but not recovery of the southern subpopulation. It is reasonable to interpret this as showing that the increase in tree cover on the margins of Cole Mere was causing the decline and that clearance of trees back from the margin has resulted in an improvement of the condition of the population. However within ten years of the cutting, tree cover along the margin is recovering to the extent that it will soon start to have an adverse effect on the *N. pumila* stands in both bays. The only way to establish effective long-term control of this fringing woodland is to grub out or paint stumps and graze the margin, this needs to be done in balance with conservation of other elements of the conservation value of the site.

Since useful records began, a maximum of three subpopulations of *N. pumila* has been known at Cole Mere. It underwent a significant decline from loss of the southern subpopulation between 1987 and 2001, to the lowest point in 2003 when only one subpopulation was found (Lockton and Whild 2006). Following cutting of trees and *Rhododendron ponticum* along the north shore, subpopulations recovered in both bays to a peak to-date of the relatively large stands present in 2016. Although these records enable some interpretation of trends in the population of *N. pumila* at Cole Mere, such interpretation is only possible at a coarse scale, based largely on the presence or absence of an entire subpopulation.

It appears that the only abundance information collected to-date on *N. pumila* at Cole Mere has involved anecdotal descriptions and estimates of the extent covered by floating leaves (e.g. Burgess, Goldsmith and Goodrich 2014). Whilst there may be a direct relationship between the number of plants or some other indication of the condition of a stand and the extent of floating leaves, this has not been demonstrated and it is therefore not possible to assess the condition of a stand, subpopulation or population in any reliable way simply by using this measure. Ideally, therefore either a different measure of the condition of populations is needed or there is a need to establish the relationship between the area covered by floating leaves and the condition of a plant.

All attempts to assess the abundance and condition of *N. pumila* at Cole Mere have involved estimates of the area occupied by floating leaves. Whilst, if accurately quantified and the method employed replicated, this information could be useful and indicate change, recording to-date has been more anecdotal, consequently only general comparisons or dramatic changes (such as the loss of the *N. pumila* subpopulation near the boat house) can be gained. In many cases, records refer to the “number of stands”, however even this is potentially ambiguous. Figure 3.1 shows the stands in the eastern bay, with one approach to sub-dividing the stand into individual units. A maximum estimate of the number of discrete units could be ten, whilst a parsimonious estimate could be five (see also Figure 3.2) but this could only be made reliable and particularly replicable through use of photographs. If in the baseline year for monitoring Figure 3.1 was used to provide a record of ten stands in the eastern bay and in a subsequent year the cover of floating leaves significantly increased, closing gaps between stands such that the maximum estimate was five stands, this would imply a decline but is much more likely to involve an improvement in the condition of the plants. Similar issues affect the use of estimates of the surface area occupied by the floating leaves of a stand. Constraints on the replication of such a measure are most readily seen from the variation in density of leaves shown in Figures 3.2 and 3.3. A change between years involving an increase or decrease in the density of the floating leaves without any change in the area occupied would not be recorded by this method but could be an indication of either an improvement or a decline in the condition of the population.

The other major constraint on interpretation of the surface area covered by floating leaves of *N. pumila* as an indication of the condition of a population is that the this parameter may not actually bear any relation to the condition of the plants. For example, it may be that dense populations produce fewer leaves (thus reducing competition between different parts of the same plant) and sparse populations produce larger numbers of leaves so that as a population declines, the area occupied by floating leaves could remain the same or even increase although the latter seems unlikely. The only way to establish the relationship between the condition of the plant and the area occupied by floating leaves is to assess the number and extent of rhizomes.

In September 2016, an attempt was made to document the submerged extent of *N. pumila* in Cole Mere. The original intention had been to undertake the submerged survey whilst the floating leaves were intact, to derive a direct comparison of the underwater parts and the floating leaves. However logistical delays meant that the submerged survey was undertaken in late September, at which point all floating leaves of *N. pumila* has broken down, although the floating leaves of *N. lutea* were still intact at this point. The submerged survey involved two divers searching the area in which floating leaves of *N. pumila* had been recorded in August, all submerged stands found were filmed. Although submerged stands of *N. pumila* were found, visibility was too poor for an accurate assessment of its distribution, area occupied or abundance. The poor visibility was mainly due to heavy growth of planktonic algae (probably actually mainly a cyanobacterium). Whilst therefore unsuccessful, this survey has shown that it should be possible to document the submerged parts of *N. pumila* in the future, to achieve this, the following steps are needed:

- People capable of diving need to be available and able to mobilise to enter the water at a day or two notice. In 2016 , the dive was made by members of the Inner Space Dive Club on a voluntary basis, they have indicated that they are prepared to be available for similar surveys in the future, however they are only available to dive in the evening or at weekends.
- People who are around Cole Mere regularly need to be able to assess water clarity and inform the divers when the water is clear enough to survey.
- A boat needs to be available to carry the divers to the survey areas.

Unless local commercial divers could be identified who would be able to respond at short notice, alternatives to the suggestions listed here seem either impractical or potentially much too expensive.

Imagery copied from Google Earth (Figures 3.2 and 3.3) show the populations of *N. pumila* in 2009 (aerial imagery taken from Google maps dated 2016, however comparison with the images listed as 2009 show that it is likely to be based on the same imagery). Two aspects of these images are striking: 1) the clarity with which the distribution and extent of *Nuphar* populations can be seen and 2) the clear distinction between *N. pumila* and *N. lutea*, evident from the density of leaves and the pattern that they form.

An understanding of the correlation between the area covered by floating leaves of *N. pumila* and the number of distinct rhizomes is fundamental to understanding whether the extent of the aerial leaves can been taken as an indication of the condition of the rhizomes and therefore of each plant. However, not only has the representation of floating leaves been employed effectively to indicate the condition of *N. pumila* in the past, but it is clear that aerial photographs provide a better indication of the extent and distribution of floating leaves at Cole Mere than any of the alternative monitoring tools. It is interesting that the equivalent imagery for Scottish sites visited is not at a sufficiently high resolution for *Nuphar* populations to be discerned, let alone identified. The difficulty of using descriptive accounts for monitoring is shown by the difficulty of reconciling descriptions of one, two and three subpopulations at different times with the evidence from 2016 images and google earth. To monitor the condition of *N. pumila* at Cole Mere, there is a need to be able to measure the population trends in a way which enables reaction to negative results before it is too late. The following options have been considered:

- Number of subpopulations - knowing that there are now two subpopulations is not enough, because on that basis the minimum trigger for a response would be loss of one subpopulation, potentially representing half of the population.
- Flowering and seed-set - possible features which would normally be used to indicate the conservation condition of stands or populations include reproductive characters such as flowering or seed-set, however as noted above, these do not seem to be important at Cole Mere and should therefore not be used as an index of population condition.
- Area occupied by floating leaves - aspects of the floating leaves may not represent a reliable indicator of condition because the number, size and area covered by floating leaves may vary in response to a range of factors and may not bear much relationship to the size of the population. That being said, the decline in floating leaves raised concerns in the early 2000s and led to some tree clearance, following this, an increase in the area covered by floating leaves suggests recovery.
- Number of discrete rhizomes - an indication of the size of the population could be gained through an assessment of the number and extent of rhizomes or rhizome clumps. However this is a poor monitoring tool as it can only be gained when the water is clear and possibly even then only by diving, which would either be expensive or complicated and thus unlikely to be reliable in the long-term.

Figure 3.4 *N. pumila* in the eastern bay, Cole Mere, August 2016

One way of combining elements of the above is through fixed point or aerial photography. In 2016, a series of photographs was taken of the subpopulation in each of the two bays along the northern shore of the mere (Figures 3.1 and 3.4) on which the area occupied by floating leaves was marked (Figure 3.1). The photographs were taken from points on the margin which could potentially serve as fixed points in future years. However it is very likely that regeneration of vegetation on the shore will make this impossible in the near future unless further work is undertaken to control regrowth. Aerial imagery from Google Earth shows the extent and distribution of both *Nuphar lutea* and *N. pumila* at Cole Mere (Figures 3.2 and 3.3). It is clear that Google Earth images are more than adequate to indicate changes in the location and extent of floating leaves of *N. pumila* and therefore that the more accurate and comparable basis for monitoring is aerial photography. It is possible that drones could be used to acquire images which would be equally useful and this option should certainly be investigated.

4 POTENTIAL FOR INTRODUCTION OR REINTRODUCTION

The limited dispersal capacity of *N. pumila* cited by various authors and the lack of hydrological connectivity to other meres, would suggest that it is highly unlikely to colonise or re-colonise other meres from Cole Mere naturally. Thus if populations are to become established in other meres, this is likely to require introduction of material from Cole Mere. This chapter presents a review of the condition of other sites where *N. pumila* is thought to have occurred in the past, consideration of potential to augment the population at Cole Mere and consideration of whether reintroduction is actually an appropriate action to take.

Figure 4.1 Kettle Mere (above left), Blake Mere (above right), Ellesmere (below left) and Crose Mere (below right) images captured from Google Earth

N. pumila has possibly been present in the past at the following sites: Kettle Mere, Blakemere, Ellesmere, Crose Mere (Lockton 2008), although this is not absolutely certain (A. Lockton pers. comm.) for some of them due to possible confusion over site names or lack of accuracy of historical records. All of these meres are at least now partially surrounded by trees on the margins. Ellesmere has some open areas maintained to enable access by the public and at Crose Mere recent tree felling has restored an open, grazed shoreline on the south east and northern sides. There is some information available on the bathymetry of these potential receptor sites from anglers and Crose Mere has been mapped by Liverpool University. Detailed bathymetry is necessary in order to plan a realistic introduction programme. If, as is the case at Cole Mere, the zone of a depth suitable for *N. pumila* is very limited, then shading is likely to be the next major factor to consider for successful reintroductions. Therefore, before any attempt at reintroduction is planned, bathymetric data need to be obtained (where this is lacking) and a long-term strategy initiated to reduce the cover of trees around the margins.

An alternative to introduction at former sites is to augment the population at Cole Mere to make it more robust and capable of tolerating changes in potentially adverse aspects such as tree shade and eutrophication. However, as is clear from Figure 2.4, the area potentially available for planting of *N. pumila* is very limited because parts of the lake less than 2 m deep are generally very shaded or subject to strong wave action. In fact, rather than planning to plant *N. pumila* into Cole Mere it would be very valuable to clear trees from the margin in areas which have not yet been cleared (particularly the north-eastern margin) and monitor to see whether *N. pumila* is able to establish without other intervention. Given the high conservation value of some of the woodland, it is important to assess whether *N. pumila* can be established in new areas before action is taken which might adversely affect this conservation value.

Figure 4.2 Overhanging trees at Blake Mere shading a stand of *Nuphar lutea* in August 2016

5 CONCLUSIONS

N. pumila only flowers in water less than 2 m deep and is supressed either by tree shade or the secondary effects of proximity to trees, such as leaf fall and litter build up.

The morphology of Cole Mere, together with the potential influence of the Sailing Club could be enough to explain the known distribution of *N. pumila* at Cole Mere, in that the southern population was in an area where rhizomes would be likely to fall from boats returning to the boat house and the populations in the northern bays are in two of few areas where shallow water occurs at points where rhizome fragments might be transported by the wind.

A long-term plan for management of the tree cover around the margin of Cole Mere is necessary, preferably taking trees back far enough from the margin that they do not shade the water and either grubbing out stumps, or treating stumps after cutting. Unless stumps are grubbed out there will be a repeated and onerous requirement for cutting natural regeneration (probably every ten years) or a risk that *N. pumila* will be lost from the site, whether or not the area is grazed.

The most effective tool for monitoring *N. pumila* at Cole Mere is aerial photography, it is likely that the most effective approach to this would be to use the drone used by the NE Field Unit.

There is a need to establish the relationship between the area covered by floating leaves of *N. pumila* and the extent and number of rhizomes. This needs to be done at intervals (e.g. every five years) to assess whether the relationship is direct and constant or variable. The current potential for collaboration between NE, the Cole Mere Sailing Club and the Inner Space Divers means that this work could be done cheaply and effectively, however there is a need for active involvement from Shropshire Council and/or NE for it to work.

Separation of *N. pumila* from *N. lutea* is relatively straightforward using the leaf size and stigmatic disk shape. In contrast, separation of *N.* × *spenneriana* from the other two taxa is far from clear and needs to be based on a combination of characters.

Both morphological and molecular evidence suggest that Cole Mere supports only *N. lutea* and *N. pumila*.

It is possible that sexual reproduction plays only a minor role in the survival and dispersal of *N. pumila*, most reproduction seems to be through movement of rhizome fragments and is therefore necessarily rarely long-range.

It appears highly unlikely that *N. pumila* will (re)-colonise other meres naturally. Therefore, if additional populations are to be established in other meres, this will have to be achieved through an introduction programme.

There is no merit in (re)-introducing *N. pumila* to other meres until bathymetric data are available to enable an assessment of the extent of potentially suitable habitat. It would also be unwise to start such a programme until long-term management of trees is initiated at each potential receptor site.

It is possible that the population of *N. pumila* could be augmented at Cole Mere. However, until a much more extensive programme of tree clearance is initiated, there is little to be gained from planting clumps of *N. pumila* into the mere.

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