The effectiveness and cost efficiency of different pond restoration techniques for bearded stonewort and other aquatic taxa

Report on the Second Life for Ponds project at Hampton Nature Reserve in Peterborough, Cambridgeshire

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1. Introduction

1.1 Hampton Nature Reserve

Hampton Nature Reserve (Orton Pits SSSI/SAC) is located in south Peterborough (UK) and covers 126ha of what is known locally as 'ridge and furrow', a unique landscape consisting of a series of over 300 ponds and their corresponding spoil heaps, created as a by-product of clay extraction for brick making (centre point TL 163943). This reserve is the last remnant of ridge and furrow, and is surrounded by housing and roads to the north and east, and farmland to the south and west (soon to be developed into further housing and industrial units). The site is now managed by Froglife in partnership with the landowner, O&H Hampton, and Natural England; figure 1: Hampton Nature Reserve

The land to the north-east and south of the reserve (Compartments R2 and H6), dating from the 1940s and 50s, includes most of the deepest ponds from the time when big clay pits were dug by hand. The excavation of clay proceeded from east to west, and although succession within clay pits is slow, over this timeframe there are distinctive differences in the succession stages of ponds between the eastern and western parts of the reserve. H6 contains the most extensive reedbeds on the reserve, whilst many of the smaller ponds in R2 have completely dried out. By contrast, the most recently dug furrows at the western edge of the main reserve were excavated in 1998, and consist of long, thin ponds with minimal fringe vegetation and an early succession flora. Most of the ridge and furrow within the main reserve (Compartments H2, H3 and CPZ) has been created since 1970, using a dragline to dredge each new furrow, with a new row being added every other year. The terrain hosts an incredibly rich topography, with every pond accompanied by a series of spoil heaps, creating a wide range of microhabitats including a vast number of ecologically important south facing slopes. The terrestrial habitat on the main reserve is a mosaic of early succession grassland, bare ground and small patches of scrub. In the older areas (Compartments R1, H1, H2 and H6) scrub colonisation is more advanced, with large thickets of dense scrub and trees added to the mosaic. The reserve also boasts a sizeable woodland called Jones's Covert, shown on 19th Century maps but likely to be much older. This wood is also a fragment of its original size, having once occupied land which is now ridge and furrow.

Many of the ponds in the complex qualify as Priority Ponds for invertebrates, and the whole site qualifies as a Flagship Ponds site, both under multiple criteria (Pond Conservation, 2009). The site also qualifies as a key reptile site under multiple criteria (Froglife, 1999), and hosts a variety of BAP priority mammal species including brown hare, harvest mouse, several species of bat as well as a large and widespread population of water voles. However, the reserve is most famed for supporting the largest extant population of great crested newt Triturus cristatus in Great Britain and possibly in Europe, estimated as up to 30,000 adults. The site is designated as a Special Area of Conservation (SAC) due to the size of its great crested newt population and because of the diversity and abundance of its stoneworts, especially the critically endangered bearded stonewort.

1.2 Objectives of the Second Life for Ponds Project

Bearded stonewort has declined in abundance and reduced in distribution on the reserve and is now considered to be in "Unfavourable Condition" by Natural England. Accordingly, conservation action is required to halt and reverse this decline. Furthermore, the unique superabundance of ponds on the reserve presented the opportunity to conduct research into the effectiveness of a wider range of management techniques than would normally be feasible for achieving this goal. However, due to the high value of the ponds to other taxa it was also important to monitor the effects of these restoration techniques on the wider ecological community.

There are therefore two mutually beneficial sets of objectives for this project. The first two relate exclusively to the conservation benefit of the restoration works to the Hampton Nature Reserve:

1.To implement the restoration and creation of ponds for the recolonisation of bearded stonewort *Chara canescens* on Hampton Nature Reserve.
2. To monitor changes, either positive or negative, within the important existing non-target taxa, including other aquatic plants and stoneworts, aquatic invertebrates, great crested newts and water voles.

These objectives will inform future management work and pond restoration cycles on Hampton Nature Reserve. Furthermore, given the extreme rarity of bearded stonewort nationally, and the importance of the reserve for other non-target species, changes to the site have a disproportionate impact on UK biodiversity targets.

The other two aims relate to the research value of the project for evidence-based conservation:

3. To evaluate four different pond management techniques - new pond creation, complete mechanical restoration, partial mechanical restoration and partial manual restoration - against a control of non-intervention, in terms of:
i) their effectiveness for bearded stonewort *C. canescens* recolonisation
ii) their side-effects on non-target taxa, including other aquatic plants and stoneworts, aquatic invertebrates, great crested newts and water voles
iii) their effect on water and substrate chemistry, and how these correlate with target and non-target taxa
iv) the cost-effectiveness of each restoration technique, considering both bearded stonewort *C. canescens* independently and the holistic effects of restoration on non-target taxa
4. To disseminate the results of the project and encourage land managers to use proven evidence-based conservation techniques on their sites

These objectives will inform land managers' decision-making throughout the wider conservation community.

The Second Life for Ponds Project was made possible through funding from SITA Trust through its Enriching Nature Programme.

The invertebrate report abridged for inclusion in this study is also available in its entirety as a separate document available from www.froglife.org/hnr/secondlifeforponds.htm
Effectiveness of different pond restoration techniques for aquatic invertebrates.

1.3 Water and substrate quality on Hampton Nature Reserve

The ponds in Hampton Nature Reserve hold water mainly derived from precipitation; as such it arrives to site at an acid to neutral pH between 5.5 and 7.2. Collecting within illite (potassium-rich post-glacial marine clay) and sandy periglacial clays, the water leaches its chemical composition from the sediments. A study of the water quality in 50 ponds in 2005 (Lambert, 2007) found them to be mesotrophic and rich in calcium, magnesium and sulphate ions which are required as metabolites for stoneworts. Such a composition reflects the marine origins of the clays, which were formed under intense heat pressure when sea levels rose following glacial meltdown. The high calcium carbonate content acts as a natural buffer which ensures a relatively stable water pH and hardness (Lambert, 2007).

This same study also indicated that the most illite-influenced clays and the lowest nutrient concentrations are found in the northeast of the reserve, whilst water coming in from west of

1a

1b

Figure 1a. **Aeria view of Hampton Nature Reserve**. Figure 1b. **Hampton Nature Reserve**. Figure 2. **Stonewort bed** in one of the ponds at Hampton Nature Reserve (note: *Chara aspera* near edge, larger *Chara aculeolata* near middle, of pond.) *Photograph: Daniel Piec*. Figure 3. **A *Chara canescens* cluster** growing on the post-glacial illite clay sediments at Hampton Nature Reserve. *Photograph: Stephen Lambert*

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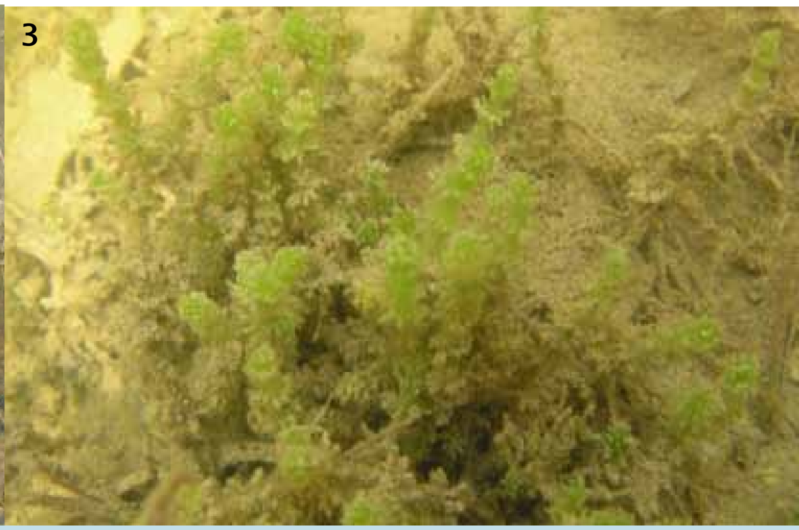


the reserve is of lower quality, being more nutrient-rich and in places adjacent to run-off from agricultural margins containing dissolved copper concentrations above those now known to inhibit charophyte persistence (Lambert & Davy, 2010). Possible causes include direct run-off from farm fields and the presence of a large flock of feral geese which graze local fields during the day and roost on the ponds at night, importing agricultural nutrients via their faeces.

This is consistent with the main causes of rural water pollution nationally, namely run-off from intensively farmed catchments and sewage effluent. Water polluted from these sources leads to eutrophication, i.e. a build up of nutrient levels in the water which encourages blooms of planktonic algae that smother vegetation, reduce light available to stoneworts underneath and deoxygenate the water when they decay.

1.4 Aquatic plants and succession on Hampton Nature Reserve

Ponds often undergo succession, as willow, reeds, rushes, and other coarse vegetation colonise their banks and shallows, and within a matter of a few years, without intervention, stoneworts tend to be limited to deeper parts of the ponds. Thankfully succession is relatively slow in the clay pits, but the process is implacable nonetheless.

Early stages of succession in the lifetime of a clay pit are characterised by abundance of stonewort-dominated communities. Their succession in the shallow ponds of the reserve starts with the wet clay being colonised by a range of stoneworts, including *Chara aculeolata*, *C. contraria* and the rare *C. canescens*, sometimes with one or two species of pondweed (often the uncommon Fen Pondweed *Potamogeton coloratus*) present.

After around five years, the deeper water has the large perennial charophytes *Chara hispida* and *C. aculeolata* or pondweed-dominated communities (usually Fen Pondweed *Potamogeton coloratus*, Fennel Pondweed *P. pectinatus* or Broad-leaved Pondweed *P. natans*). Bearded stonewort becomes increasingly confined to the shallow margins, where it is usually mixed with *C. aspera*. Here, bearded stonewort can persist where there are gaps in the emergent vegetation, but even these eventually close over after about 20 years.

In these later stages vascular plants such as pondweeds *Potamogeton* spp, Mare's-tail *Hippuris vulgaris*, Spiked Water-milfoil *Myriophyllum spicatum* and Horned Pondweed *Zannichellia palustrisbe* become more dominant (Crick *et al.*, 2005). Over time, as the ponds begin to silt up, swamp vegetation encroaches from the margins leading to the formation of reedbeds and accelerating the speed at which ponds dry up.

1.5 Aquatic invertebrates on Hampton Nature Reserve

Brick pits in the Peterborough area support exceptional assemblages of aquatic invertebrates, in terms both of number of species and the representation of rarities. The most important water bodies are moderate to small ponds of no great depth, including very small shallow seasonal pools, though even the large lakes are not devoid of interest. Interest is taxonomically widespread, except that the ponds tend to be markedly poor in molluscs and leeches. Overwhelmingly the greatest interest lies in the water beetles. Hampton Nature Reserve is the richest single site for aquatic invertebrates in general and for water beetles in particular, with more than 120 species of water beetle recorded. The particularly high interest of Hampton Nature Reserve seems to stem largely from the number and variety of ponds rather than from any other characteristic particular to the site: almost all of the recorded species are known elsewhere in the area. Invertebrates associated with water margins and emergent vegetation perhaps have a better claim to unique character at

Hampton, but this may in part result from under-recording elsewhere, since such groups are less easy to record, and less recorded, than aquatic species.

It is clear, and unsurprising, that there is considerable variation in the amount of interest and the rate of development of interest in these ponds according to size, depth, situation, and degree of isolation from colonizing wetland vegetation, but a few generalizations are possible.

- Provided they are isolated from sources of polluted water, such ponds invariably develop significant invertebrate interest.
- Though early colonists arrive rapidly after the creation of ponds, the progress of colonisation is slow. Isolated ponds to which no vegetation is deliberately introduced may have no more than a handful of established macroscopic invertebrate taxa in the first year.
- Increase in invertebrate diversity is closely correlated with colonisation by vegetation and increasingly complex vegetation structure. The rate at which vegetation, and thus invertebrate diversity, develops varies considerably between ponds, but for a 'typical' new pond, of moderate size, simple outline, and containing permanent water in its deepest parts, an expectation of five years to the development of something approaching peak diversity is reasonable; it can be more, but is unlikely to exceed ten years.
- Interest can remain high for a substantial time, especially if aided by considerable seasonal fluctuations in water level, local trampling or grazing of the margins or a deep central basin in which emergent vegetation cannot easily grow.
- The richest ponds, with varied vegetation structure, contain a mix of invertebrates with very varied requirements: many early colonists, with a requirement for bare margins and open water, can remain for as long as suitable conditions exist over part of the margin, and can co-exist with species requiring dense vegetation, including dense beds of emergents. However, some pioneer species may be rapidly lost, perhaps more as a result of competition with later arrivals than because of the absolute unsuitability of conditions.
- Serious decline in the pond invertebrate assemblage comes with shading, either by dense and continuous beds of emergent plants (especially reed) or marginal shrubs and trees, or with a build-up of organic material and anaerobic decay in the sediments: the two are often closely associated. Brick pit ponds tend to be slow to develop such conditions. This in part is the result of generally slow succession change, but also because several of the commoner emergent plants in brick pit ponds tend to produce fairly open-structured stands, often not very tall, which do not cast heavy shade. The build-up of organic sediments seems also to be unusually slow: a brick pit pond may contain large amounts of plant debris in the form of dead stems and leaves of emergent plants without a serious build-up of anaerobic conditions in the underlying sediments. This is most likely due to the low nutrient concentrations within the ponds and hence reduced algal die-off which contributes to sediment accrual. Large seasonal fluctuations in water levels allowing desiccation and oxidation of the pond wall are also probably an important factor in maintaining such conditions.

Substantial invertebrate assemblages often co-exist with large beds of stoneworts in brick pit ponds. Indeed, stoneworts provide a well-structured habitat for many invertebrates, and some feed partly or entirely on them. However, the most stonewort-dominated ponds are rather too open-structured to support maximal densities and diversity of invertebrates. Indeed, it is temptingly possible to suggest that, as a rule of thumb, the point at which the increase in aquatic invertebrate population density and diversity begins to level off is the point at which stonewort interest is definitively past its best. Invertebrate interest may remain high long after stoneworts have been almost or entirely lost, and even after the aquatic fauna begins to decline, interest in the terrestrial and semi-terrestrial fauna may remain, or even increase. On a site which is important for both botanics and invertebrates, the dove-tailing of their requirements is therefore a matter for careful consideration. Both groups require, for the maintenance of a full assemblage of species, the maintenance or regular recreation of early succession stages, but the preferred balance of the various possible stages and structures may differ.

1.6 Great crested newts

Great crested newts favour large ponds, including both deep areas and shallows, with a shallow gradient, and abundant submerged, floating and emergent vegetation (Rannap & Briggs, 2006; Langton *et al*., 2001), with between 65-80% vegetation cover identified as ideal (Oldham *et al*., 2000). Despite this preference, great crested newts can also occupy and breed successfully in ponds with hardly any vegetation, especially shortly after a complete or partial pond restoration, with egg laying occurring on bare ground (Phil Parker, pers. com.; pers. obs.). However, these kinds of condition cannot be optimal due to the higher risk of predation, less abundant invertebrate prey and the lack of suitable egg-laying plants.
Complete pond restoration would in normal circumstances be judged a quite drastic measure for newts, and especially for the invertebrate fauna on which they feed. The good practice guidelines for restoring great crested newt ponds adopted a much gentler approach based on partial restoration methods (Langton *et al*., 2001).

There is therefore a potential conflict between management for stoneworts, which require early succession bare clay habitat and disturbance, and management for great crested newts, which benefit from more mature ponds.

1.7 Water voles

Hampton Nature Reserve is a stronghold for water voles. Surveys carried out in 2008 and 2009 by Froglife volunteers found water vole signs (recent feeding stations and latrines) extensively throughout the reserve; almost every pond showed signs of water vole occupation. The long narrow shape of many of the ponds, with 'wavy' banks, is ideal for water voles as it maximises the area of marginal vegetation which the voles need for food and cover. The steep clay banks provide a good substrate for above and below water burrow systems, and most of the ponds are well vegetated as they approach mid to late succession. Furthermore the size and shape of this pond complex, coupled with the often heavy reed and emergent vegetation, make this population much more resistant to invasion by mink - a process which is beginning in H6 and is under review (Pond Conservation, 2010; Carter & Bright, 2003).

Habitat management is important in the long run, even for this mid-late succession species, in order to prevent succession to reedbed or carr woodland and drying up of the ponds. Strachan & Moorhouse (2006) recommend partial restoration on a rotation for long-term maintenance of habitat, as this leaves refuges undisturbed. Given the importance of emergent vegetation for water voles complete restoration of ponds or ditches goes contrary to best management practice - indeed, on small or isolated sites it could wipe out a colony. While this dovetails with management recommendations for great crested newts (see 1.6) it may be in conflict with management intended to maximise the area of early succession habitat for stoneworts.

We can proceed with the experiment confident that the population level risk to water voles from potentially adverse habitat management is minimal because of their widespread presence on site and because of the abundance, structure and layout of ponds on Hampton Nature Reserve.

1.8 Stoneworts (Charophytes)

1.8.1 General

Stoneworts derive their name from the calcified crust which many species produce as a by-product of carbon uptake, which results in a crunchy feel to the touch. They are a unique form of algae which have a complex structure. Despite being algae, their morphology may often resemble that of higher plants, but they have no vascular system for nutrient and mineral transport within the plant.

They vary in size from a few centimetres to over a metre tall and have a characteristic appearance with whorls of linear 'branchlets' along their stem - rather like underwater horsetails. Indeed, early botanists classified them with horsetails in the genus Equisetum. Modern DNA analysis techniques have since shown that stoneworts represent the evolutionary link between algae and vascular plants.

Stoneworts do not possess a classic root system and import most of their nutrients passively through their surface cells and up through their rhizoids (filamentous anchorage hairs in the sediments). This makes them very sensitive to water quality, particularly in relation to elevated concentrations of nitrates, phosphates and heavy metals. Recent research has shown that dissolved nitrate from agricultural sources poses the greatest threat to charophyte populations and habitats in the UK through the stimulation of competitive vegetation and direct toxicity at concentrations higher than 2.5mgl-1. Dissolved copper from agricultural sources is ranked as the second highest threat, and dissolved phosphate was also found to pose a risk at concentrations as low as 100mgl-1, at which concentration fecundity has been shown to be reduced, both in the field and in laboratory trials (Lambert, 2010). The sensitivity of stoneworts to nutrient enrichment and heavy metals make them exceptional indicators of water quality. They have been described as the 'canaries' of freshwater ecosystems.

Due to their fine structure they have a high biomass per unit volume of water and can sequester large concentrations of nutrients from the water which they retain for long periods due to their slow rate of decomposition when dead. They also help to clarify the water by stabilising sediments, and have been shown to release chemicals containing sulphur that inhibit the growth of other algae, thereby providing some buffering against eutrophication.

Their large surface area is colonised by micro-organisms which support a diverse invertebrate population, even throughout the winter, when other macrophytes have died back.

When their spores fall, if they do not germinate within two or three seasons they become encrusted with calcium salts, making them extremely durable. Such spores have been found as fossils dating back to the Silurian period around 400 million years ago. Recently such spores dated at over 100 years old have been germinated, demonstrating both the resilience of stoneworts to adverse conditions and the potential for reduced or lost populations to be restored from the spore bank, should environmental conditions improve (Davy et al., in prep.). This indicates that, so long as the water quality has not degraded, vegetative stonewort colonies will regenerate from the oospore bank if habitat management exposes and re-floods bare sediments.

There are about 400 species worldwide, of which 30 are native to Britain. A Red Data Book for Stoneworts was published in 1992 - the first to cover a group of lower plants. 45% of British stonewort species are under threat and more than half are classified as rare. These proportions are considerably higher than for most other groups of organisms and reflects a general decline in standing water quality. Most species have declined to a greater or lesser degree and this trend seems to be continuing; 17 species have been identified as Priority Species in the UK Government's Biodiversity Action Plan (BAP).

1.8.2 Stoneworts on Hampton Nature Reserve

Hampton Nature Reserve boasts 10 species of stonewort, making it the second most diverse stonewort site in England. Five of the species present are listed as Nationally Scarce, and one - bearded stonewort *Chara canescens* - is a BAP Priority Species and is protected under Schedule 8 of the Wildlife and Countryside Act 1981.

Table 1. **A list of stonewort species recorded on the reserve**

Scientific name	English name
Chara aspera	Rough stonewort
Chara canescens	Bearded stonewort
Chara contraria	Opposite stonewort
Chara curta	Lesser bearded stonewort
Chara hispida	Bristly stonewort
Chara aculeolata	Hedgehog stonewort
Chara virgata	Delicate stonewort
Chara vulgaris	Common stonewort
Nitella flexilis agg.	Dark stonewort
Tolypella glomerata	Clustered stonewort

1.9 BEARDED STONEWORT CHARA CANESCENS

1.9.1 Ecology of bearded stonewort *Chara canescens*

Bearded stonewort is critically endangered. Apart from Peterborough, in the UK this species is only found on one brackish marine site in the Western Isles of Scotland (Moore, 1986).

Recent research into the autecology of *Chara canescens* locally has revealed that the plant is associated with freshly scraped sediments which have a pH in excess of 8 and a positive redox potential - these factors may be specific keys for germination of the oospores (Lambert, 2007). On Hampton Nature Reserve it is associated with the youngest ponds and with areas of older ponds that have recently exposed sediments. As soon as the surface of the sediments ages and the pH drops in tandem with the redox potential, the populations decline regardless of the presence or absence of competition from other plants. In a national survey of 123 water bodies important for stoneworts (Lambert, 2007) species tended to zone or occupy niches of specific sediment pH and redox intervals, and this is very likely to be critical to the re-emergence or longevity of *C. canescens* populations at Hampton Nature Reserve. The same study indicated that the most favourable conditions for *C. canescens* on the reserve were found in the north-eastern ponds, where the highest density of *C. canescens* oospores are found (See 1.3).

1.9.2 Decline of bearded stonewort *Chara canescens* on Hampton Nature Reserve

Despite the slow succession rate of pond vegetation on the reserve, recent monitoring results suggested a degree of nitrate and phosphate pollution and a faster decline in the range, pond occupancy and abundance of bearded stonewort than had previously been anticipated. Within six years there has been nearly a 75% reduction of occupied ponds, from 98 in 1999 to just 28 in 2005, with bearded stonewort abundant to dominant in none (compared to 34 in 1999).

Alongside this the range of bearded stonewort has been steadily contracting. Table 2. shows the eastern limit of bearded stonewort in the main reserve over time, excluding ponds where there has been recent disturbance. These show a gradual migration westwards from the eastern limit resulting from succession of the ponds (the ponds get progressively older towards the east). Less predictable was a marked decline in the youngest ponds nearest the old workface (rows 02, 01 and 1) which were expected to be the last stronghold of bearded stonewort in the absence of management. However, it is not until row 3 that bearded stonewort is locally abundant. This is likely to be due to agricultural run-off and the presence of large feral geese flocks (See 1.3).

Table 2. **Eastern limit of bearded stonewort in previous surveys** (dates, pers. comm. T. Langton)

Survey date	Oldest undisturbed pond containing bearded stonewort in main area	Approximate date of creation
1990	Row 37	1972
1995	Row 32	1974
1999	Row 24	1977
2005	Row 16	1982

1.10 Case Study: Stonewort Pond Creation at the Whittlesey Brick Pits

Experimentation with restoration of existing ponds was favoured on Hampton Nature Reserve due to the large number of ponds in unfavourable condition for *Chara canescens* and the general trend towards ageing ponds within the reserve. Furthermore there is limited space for new pond creation, although this technique was included for comparison.

By contrast land managers at Whittlesey Brick Pits, Peterborough, created new ponds and scrapes for translocation of *Chara canescens* and investigated different translocation methodologies. A summary of this supplementary work has been included as a case study.

2. Pond locations: Management clusters

The project combined practical habitat management with research and therefore required multiple ponds, 15 in total. Despite the presence of over 300 ponds on the reserve, the topography of the ridge and furrow terrain meant that it was difficult to choose a single section of the reserve with the required number of ponds easily accessible for an excavator. During the initial field visit it was decided to conduct the experiment in three clusters, so that conditions within each cluster would be as uniform as possible
(Figure 4).

While efforts were made to pick ponds of similar physical dimensions and succession stages within each cluster, access for machinery and volunteers constituted an overriding selection criterion. Four ponds were selected, plus a fifth which was newly dug, in each cluster.

Given the difficulty in finding groups of reasonably homogenous ponds, even within a cluster, a cluster of ten new 'standardised' ponds was dug in the north area of the CPZ. These ponds were of similar size and depth, roughly 7-10m diameter and no more than 1m deep. They were dug in two rows of five separated by 5-10m. These ten ponds could be regarded as a fourth cluster of ponds, although they do not play a direct part in this experiment. They lay the foundations for future experiments into the rate and character of succession and follow-up management studies.

The map below shows the position of each cluster relative to the others, but does not show the ten new ponds in Cluster 4 which were dug in the north-western part of the reserve in Compartment CPZ, due west from Cluster 2. The following sections detail the physical characteristics and succession stages of each of the selected ponds.

2.1 Cluster 1 (Compartment R1)

Cluster 1 (Figure 5) was located in the north of the reserve in Compartment R1, higher than the other two clusters, with ponds R6 and R7 being the oldest ponds of all those selected. Despite their age, emergent vegetation was confined in both cases to the south edges of the ponds, in the shallows on low grade slopes. The remaining areas of the ponds were occupied by a dense mixture of submerged plants, the majority of which were stoneworts. The maximum depth was approximately 1.5 metres and bare ground was rare in these two ponds. Both ponds had crystal-clear water. Partial manual clearance in Pond R7 did not cause a serious turbidity problem and the pond cleared after a few days.

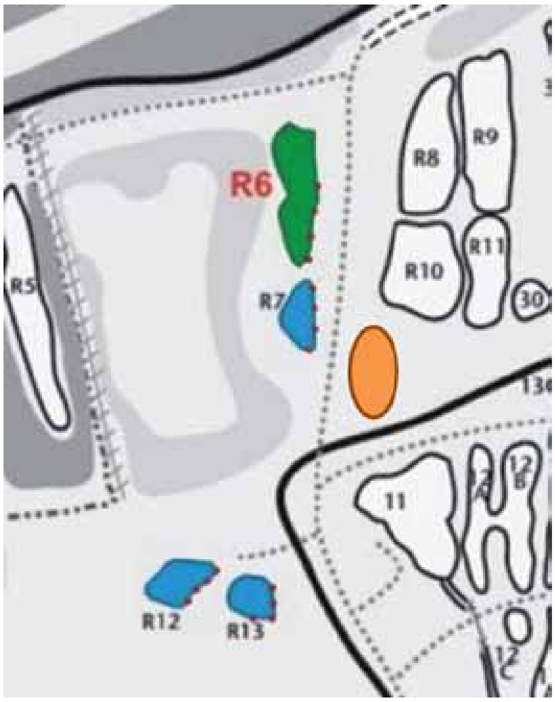
Ponds R12 and R13 had been dug more recently, around ten years ago. Despite their relatively young age, the ponds were heavily overgrown by reeds and bulrushes, perhaps due to their gentler slopes. At the same time, both ponds supported very good stonewort beds, including bearded stoneworts. The turbidity in these ponds was very low, although pond R13 remained heavily turbid after the complete clearance throughout the spring and cleared only in May. The partial mechanical treatment did not cause any long-term turbidity problems; they were only local and temporary.

The new pond was created in a natural dip where the water usually gathered, often flooding the track. The pond was similar in size to pond R7 and was a maximum of 1 metre deep. Turbidity was quite bad throughout the season but improved slightly in May 2010.

Pond R6 (control pond): **TL 16410 94860**
Pond R7 (partial manual clearance): **TL 16415 94810**
Pond R12 (partial mechanical clearance): **TL 16390 94705**
Pond R13 (complete clearance): **TL 16430 94695**

Figure 4: **Overview map of selected ponds for management and surveying**
Ponds marked in blue = managed ponds.
Ponds marked in green = control ponds.

Figure 5: **Location of ponds in Cluster 1 (Compartment R1).** The successful new pond is marked in orange.



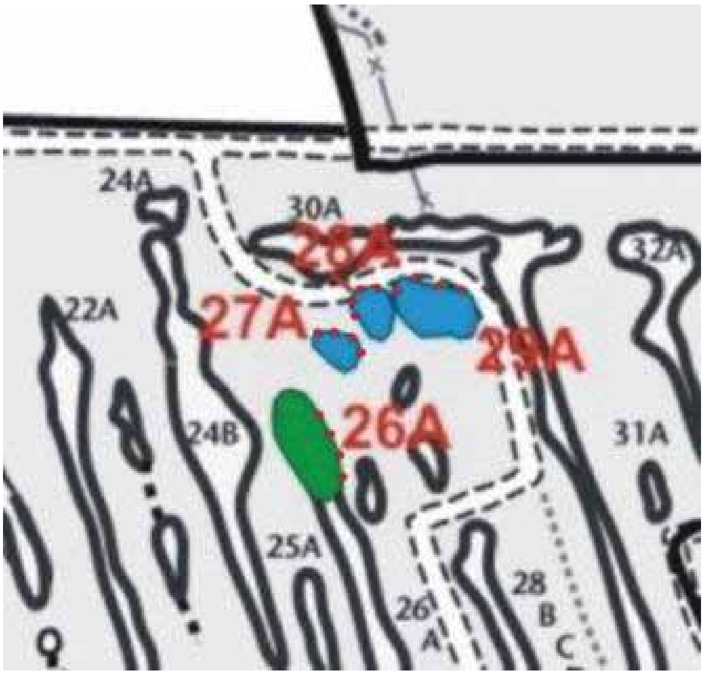


Figure 6: **Location of ponds in Cluster 2 (Compartment CPZ).**

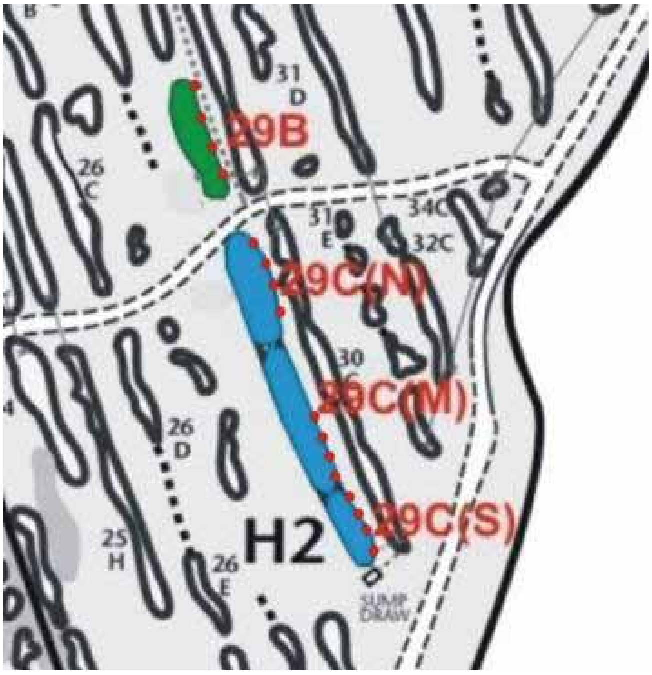


Figure 7: **Location of ponds in Cluster 3 (Compartment H2).**

2.2 Cluster 2 (Compartment CP2)

Located lower than Cluster 1, in the north part of the main reserve, Cluster 2 (Figure 6) contained some of the deepest ponds within the study. The control pond 26A was the shallowest within the complex with clear water and at a medium stage of succession. Pond 27A (complete clearance) was completely overgrown by bulrushes, to the extent that it periodically dried out. This pond was quite clear in spring 2010, especially towards the end of the season.

Ponds 28A and 29A were similar to each other, oval in shape and quite deep (up to 3 metres). Additionally, they had steep banks, especially pond 28A, which affected the regeneration of stoneworts and made it less suitable for invertebrates. These two ponds had very clear water and, despite their depth, it was possible to see the bottom of the ponds. Partial mechanical and manual clearances disturbed the water quality temporarily, without affecting the pond ecosystem.

The new pond failed due to leakage and limited catchment.

Pond 26A (control pond):	**TL 16150 94520**
Pond 27A (complete clearance):	**TL 16150 95540**
Pond 28A (partial mechanical clearance):	**TL 16165 94555**
Pond 29A (partial manual clearance):	**TL 16180 94560**

2.3 Cluster 3 (Compartment H2)

Ponds in Cluster 3 were all located along a single ridge (ridge 29), all ponds being long and narrow and varied in depth (1-2 metres). The control pond 29B was located to the north of the complex and was clear and shallow, at a medium stage of succession. Ponds 29C(N) and 29C(M) were separated from each other with a soil bank made during habitat management. This was done to keep water quality as similar as possible in these two ponds. Unfortunately, the barrier was flooded in spring 2010 just over a year after the habitat work. These two ponds had clear water and the emergent vegetation developed only in shallows along approximately 20-30% of the pond edge. The manual and partial clearances did not dramatically change the water quality and the ponds returned to a stable state after a few days.

The complete clearance in pond 29C(S) was much more dramatic in terms of water quality: turbidity remained very high until May 2010.

The new pond failed due to the limited catchment.

Pond 29B (control pond):	**TL 16310 94290**
Pond 29C(N) (partial manual clearance):	**TL 16320 94255**
Pond 29C(M) (partial mechanical clearance):	**TL 16345 94185**
Pond 29C(S) (complete clearance):	**TL 16360 94150**

2.4 Cluster 4 (Compartment CP2)

These ten ponds rely exclusively on rain water as they are surrounded by a small bund. This was necessary to prevent potential fish expansion during flooding events and to protect the new ponds from agricultural run-off. The majority of the ponds were very dry or completely dried out during summer 2009, but were full during heavy rains and over the autumn/winter season and nine of them have held water constantly throughout 2010 since then. Turbidity was quite low.

3. Habitat Management Methodology

Habitat management was undertaken between October 2008 and January 2009. The mechanical part of the work (new ponds, complete clearance and partial mechanical clearance) took place in October and was completed within seven days. A 30-ton excavator was used; a large machine was required due to the large amount of soil which needed moving to gain access to the ponds. A long-reach arm was needed for some of the ponds to ensure complete clearance. A 30-ton dumper truck was hired to distribute the spoil and sediment around the reserve and a large diesel pump to lower the water level in ponds designated for complete and partial clearance.

A few days before the habitat work started as much water as possible was pumped out to facilitate access to the pond base. The end of the delivery hose was fixed with a safety net, so that any potential fish would not be translocated. To the best of our knowledge all of the ponds selected were fish-free. All the areas where machinery would operate were also checked for any potential resting and/or hibernating newts. All amphibians found were moved outside the operating range of the machine, and put in comparable places of shelter.

Following baseline water quality and species surveys the following restoration methods were undertaken in clusters 1-3:

1. Control pond - no management was applied.
2. Partial manual clearance with the assistance of volunteers (15 metres of the pond edge).
3. Partial mechanical clearance with an excavator (15 metres of the pond edge).
4. Complete mechanical clearance with an excavator: the sediment and vegetation were scraped.
5. New pond creation - a completely new pond was excavated. Space restrictions limited the possibilities for excavation of new ponds. As a result two of the three new ponds failed - only the new pond in Cluster 1 succeeded. Two of the new ponds from Cluster 4 were used in some of the surveys as surrogates, although it must be noted that they both fall outside their parent clusters. All new ponds are described in 2.4.

Restored ponds were scraped to the level of bare clay, removing the organic build-up from the base of the pond. Partial restoration extended up to about 2 meters towards the centre of the pond, about 0.5 meters up the pond bank, and to no standard depth, with exact values dependant on water levels and the gradient of the pond edge. Where possible the shape of the completely and partially cleared ponds was retained and only deepened.

A toothed bucket was used to provide a more diverse surface on which stoneworts could regenerate. The spoil from digging new ponds was used to create low banks nearby or around the ponds. Similarly, the sediment from pond clearance was distributed in small piles away from pond edges around the reserve in order to minimise the risk of nutrient leaching into the ponds. Initially, the dumper truck was used, but because of poor surface conditions it kept getting stuck so the digger had to be used instead.

The manual work was undertaken over several sessions by the Hampton Nature Reserve Volunteer Group. The work was carried out using spades, forks and rakes - sludge was removed until the fresh layer of clay was visible. The work proved to be a tough and monotonous task which sapped their enthusiasm over a few sessions. We also engaged two volunteer groups from the Environment Agency who approached the task with a fresh enthusiasm.

8

9

Figure 8a. **Excavator and dumper truck** working to completely restore pond R13 in Cluster 1; 8b: **Complete mechanical clearance of pond 27A.** Figure 9: **Volunteers working** to partially clear pond R7 in Cluster 1

8b

4. Survey Methodology

All the selected ponds were monitored for water quality and surveyed for bearded stonewort and non-target taxa during Autumn 2008 (except great crested newts as it was too late in the season), to provide a baseline dataset prior to any management work. The project's holistic approach to pond restoration required the involvement of specialists including an entomologist, botanist, vertebrate and freshwater ecologists. The following taxa were surveyed:

- bearded stonewort *Chara canescens*
- other stoneworts
- other aquatic plants
- aquatic invertebrates
- great crested newts
- water voles

After restoration, monitoring continued with four follow-up surveys conducted at three-month intervals in Spring 2009, Summer 2009, Autumn 2009 and Spring 2010 for invertebrates, plants and water quality; water vole surveys and great crested newt surveys were omitted in Summer and Autumn 2009 respectively, representing a suboptimal survey period for these species.

Some surveys were undertaken on the scale of managed area and others on whole pond. However, to be standardised all ponds had 15m sample stretches marked in the field to enable direct comparison with the partially restored ponds. Repeat surveys were carried out in the same stretch of pond. On partially restored ponds this area corresponded to the restored area whilst on all other ponds the selection of the 15m sample area was more arbitrary and determined in part by ease of access.

The 15m sample stretches were further divided into three 5-metre sections (See Figure 10), marked with stakes as shown with red dots on the maps in Section 2. Ultimately, however, due to the variability in data, records from the whole 15m sample stretch (water samples and quantitive invertebrates) or from the whole pond (invertebrate inventory survey, botany, newts and water voles) were pooled for analyses.

4.1 Stoneworts and aquatic plants

The upper (vertical) limit of vegetation recording in water bodies is difficult to define in such a way as to make the survey replicable in a meaningful way. For the purposes of this series of surveys, the limit is defined using an always-replicable physical feature, i.e. the wetted area. This means, in practical terms, that all plants recorded are in physical contact with the water at the time of survey. This method has been chosen because it is always replicable and is considerably more practicable than permanently marking out the recording area, the only realistic alternative.

There are clearly drawbacks with this approach, related to water level fluctuation, which must be taken into account when interpreting the results:

- If water levels fluctuate widely, plants recorded in one survey may not be recorded in another, although present both times. If we assume that water levels fluctuate more or less equally within a cluster then this effect can be taken into account by comparing managed ponds to the control pond.
- The area of the pond will vary with the water level and this affects abundance estimates, particularly for emergent, rooted marginals which tend to form more or less constant stands. For this reason only stonewort data is analysed using percentage covers, as they are an assemblage of submerged plants which are less affected by water level fluctuations.

All plant species observed in the wetted area of each pond were identified to species (where practicable) and their percentage cover estimated by eye. Percentage cover was repeatedly estimated by the same expert for all species occurring in each sample strip (see Figure 10). The occurrence of a species and its cover value in each strip pertain to an area defined by:

- the edge of the wetted area.
- lines perpendicular to the margin of the pond at each end of the sample strip.
- the line of greatest depth connecting the lines at each end of the sample strip.

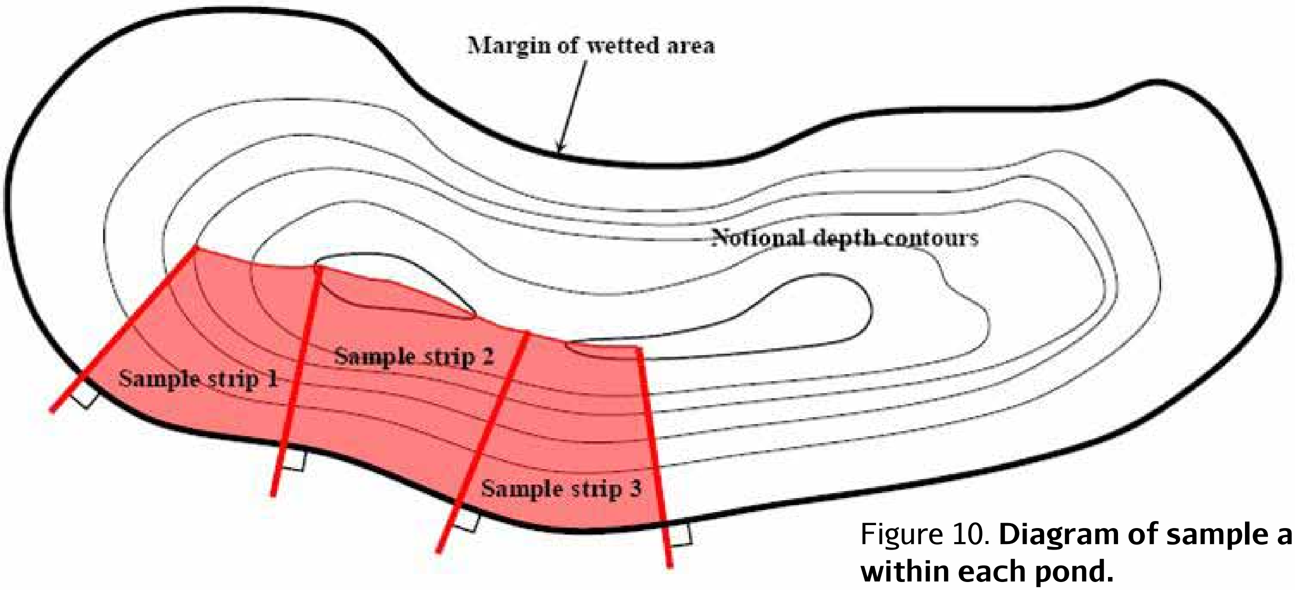


Figure 10. **Diagram of sample areas within each pond.**

The delineation of the sample areas in this way has implications for the interpretation of results:

- The occurrence or abundance of species between sample strips at any one survey event is not comparable, within or between ponds.
- The occurrence or abundance of species between sample strips is not comparable between survey events, within or between ponds.
- Comparisons may only be made between survey events by sample strips or by grouped sets of strips.
- Grouped sample strip data across management treatments may be compared with grouped sample strip data within management treatments to assess the extent of the effects of the different treatments.

4.1.1 Timetable of work

Baseline Survey Autumn 2008	10 October	All clusters
Spring 2009	1 April	All clusters
Summer 2009	5 September	All clusters
Autumn 2009	17 October	All clusters
Spring 2010	21 April	All clusters

4.2 AQUATIC INVERTEBRATES

4.2.1 Target groups and nomenclature

Only aquatic invertebrates have been examined in this study, and since there is no definition of 'aquatic' invertebrates which is both straightforward and useful, the groups recorded in practice can be seen from the list of target groups below and from the species list (see Appendix 1).

The following invertebrate groups were identified if found, and the following sources have been used as the basis for nomenclature in this report, though occasional changes subsequent to the listed works have been incorporated:

Target groups	Nomenclature
Tricladida (flatworms)	Reynoldson & Young, 2000
Mollusca (water snails and mussels)	Anderson, 2005
Hirudinea (leeches)	Elliott & Mann, 1979
Larger Crustacea	Gledhill *et al.*, 1993
Araneae	Harvey *et al.*, 2002
Coleoptera (beetles)	Duff, 2008
Diptera (flies - to family or genus only, except for Cylindrotomidae, Dixidae, Stratiomyidae)	Chandler, 1998
Ephemeroptera (mayflies)	Macadam, 2001
Hemiptera (bugs)	Aukema & Rieger, 1995-2006
Lepidoptera (moths)	Bradley, 1998
Megaloptera (alder-flies)	Plant, 1997
Odonata (dragonflies)	Merritt *et al.*, 1997
Trichoptera (caddisflies)	Edington & Hildrew, 1995; Wallace *et al.*, 1990

Note was also made of the presence of Oligochaeta and Hydracarina.

4.2.2 Timetable of work

The aquatic fauna can be readily, easily, thoroughly and consistently recorded as described below, although sediment fauna, including known rare species, are under-sampled due to sampling constraints in order to not interfere with the management effects.

Samples to provide baseline data on the invertebrates of the ponds to be managed, and those selected as controls, were taken in October 2008. For each pond, an overall inventory of the fauna was made, and quantitative samples were taken from each of the marked five-metre stretches. Quantitative sampling was repeated in the spring, summer and autumn of 2009 and the spring of 2010. Inventory samples were taken from new and entirely mechanically cleared ponds in autumn 2009, but they included no species which were not also recorded in the five-metre stretches, so have not been separately reported.

Baseline Survey Autumn 2008	10 October	Samples from Clusters 1 & 2
	11 October	Samples from Cluster 3
Spring 2009	18 April	Samples from Clusters 1 & 2
	20 April	Samples from Cluster 3
	10 May	Samples from Cluster4
Summer 2009	25 July	Samples from Clusters 1 & 2
	26 July	Samples from Cluster 3
Autumn 2009	29 October	Samples from Clusters 1 & 2
	30 October	Samples from Cluster 3
Spring 2010	10 April	Samples from all ponds

4.2.3 Inventory survey methods

No reasonable amount of sampling of any pond with a rich fauna will produce a complete species list. As a definable and reasonably achievable target for the preparation of an inventory for each pond, recording was as far as possible exhaustive for water beetles (i.e. recording continued until capture of new species has apparently ceased, and involved sampling of all habitat components within and at the margins of the pond) with all other readily identifiable invertebrates captured during the sampling also identified. The sampling method was as follows:

- deeper water in each pond was sampled using a standard pond net of side twenty-four centimetres and mesh size one millimetre;
- water margins and dense vegetation in shallow water were sampled using a plastic sieve of seventeen centimetres diameter, with a mesh size of two millimetres (giving holes of approximately one millimetre);
- fine, bare and thinly vegetated sediments were sampled using a small sieve, eight centimetres in diameter and with a mesh size of 0.5 millimetre;
- representative bulk samples obtained by the larger pond net were examined in the net and large and obvious animals extracted immediately;
- net samples from representative areas were spread on metal grids of mesh size 5 millimetres suspended over plastic trays, and active animals allowed to make their own way through the grid for a minimum of ten minutes;
- material remaining in the sieve was then sorted for less active invertebrates, such as molluscs, and additional larger individuals unable to fit through the mesh of the grid;
- representative portions of the material from both the larger net and the sieve were immersed in water to encourage activity in those taxa, such as caddisflies, which are infrequent in sieve-sorted samples.

No precise length of pond margin was used for sampling; sub-samples were taken from a number of points chosen both to reflect the character of the pond and to include the areas which seemed likely to hold the richest fauna. The 15m marked management/control stretches were not included in the inventory sampling.

An estimate was made of the frequency of each recorded taxon in the sample from each pond. If only one or two individuals of a species were captured, the actual number was recorded. A three-point scale was used beyond this: occasional (3 - 10); frequent (11 - 100); common (more than one hundred).

Almost certainly, the greatest source of error in estimating abundance at the lower levels of the scale is simply failing to notice some individuals of some species, and at the higher levels making poor estimates of numbers of individual taxa amongst the general mass of material; under-estimates of frequencies are likelier than over-estimates. The abundance codes are intended to give only a general impression of relative frequency of the different species.

4.2.4 Quantitative sampling methods

Samples were taken from the central three metres of each five-metre stretch (see Figure 10) to avoid contamination from adjoining stretches. In the well-vegetated state of the ponds at the time of taking the first samples this is excessively precautionary, but in ponds with little or no vegetation after management, animals disturbed by sampling may easily and rapidly swim, or drift in an induced current, for distances of a metre or more.

In each five-metre stretch, a sample was taken using a standard pond net at three different depths, along lines parallel with the pond margin. The first was along the margin itself; the second at a depth equal to the breadth of the net frame; the third further from shore, but at a less precise depth, an inconsistency forced by variation in pond profile and vegetation. Where there was a distinct change in vegetation - typically, the cessation of a dense marginal fringe - the final sample was taken beyond the point of change; where there was no obvious change in the vegetation structure the sample was taken in deeper water at the limit of net reach (using a net and handle two metres in length) from the shore. Each three metre stretch was gone over three times: on the first pass, from right to left, the net was worked to disturb the vegetation and, where exposed, the surface of the mud; on the second and third, made from left to right and right to left respectively, the net was moved at a steadier rate over the same track. Where emergent vegetation was open or sparse, the entire three-metre stretch was sampled in three complete passes; where vegetation was very dense, and sampling slow, the sampling was done over shorter sub-stretches, with three passes over six successive half-metre samples in the densest areas. In shallow water, the net contacted the bed of the pond, but was not allowed to dig in. The net was emptied into a tray of water at the end of each three-metre transect. Large pieces of vegetation (especially long lengths of dead stems, but also large pieces of pondweed and stonewort) were removed to a separate tray of water, rinsed thoroughly, brushed with a nylon-bristled paintbrush where there was a dense covering of material which might make rinsing alone inefficient in removing attached organisms, and discarded. Remaining material from each of the trays was then strained through a 0.5mm mesh sieve, and the sieve contents placed in a polythene bag. Material from the three transects in each five-metre stretch was combined in a single bag as a bulk sample, preserved with formalin, labelled, and sealed for later sorting and identification.

A further minute was devoted to sampling with sieves in denser vegetation in each five-metre stretch, searching for water beetles especially, but also bugs, which are liable to be under-recorded by standardised sampling with a large net. Collected material was placed on the 5mm metal grid and animals allowed to make their way through for several minutes, after which large and easily identified species were noted, and representatives of the remainder were removed, preserved in 70% iso-propanol in a tube, and sealed into the bag with the quantitative sample from the same stretch. This sampling was not wholly consistent in character between samples, and was consciously aimed to fill likely gaps in the species lists. Invertebrate species were recorded simply by presence. The invertebrates taken in this way are not strictly part of the quantitative sample, but provide further data for comparison of the overall fauna in the fifteen-metre sample stretch and other parts of each pond, and potentially add to the overall inventory list for the pond, especially if any species occur in sample stretch but not in the remainder of the pond.

4.2.5 Sample sorting and identification

Organisms for the inventory survey which were preserved in the field in iso-propanol, and which were kept in a single container for each pond, were emptied into a Petri dish and identified directly under a binocular microscope. Formalin-preserved bulk samples from inventory sampling were poured into a 0.5mm mesh sieve and rinsed thoroughly in tap water, then immersed in water in an oval white ceramic dish for examination under a binocular microscope. As much material as possible was identified immediately; organisms requiring dissection or drying for certain identification were removed to Petri dishes and examined separately.

The contents of each bag of preserved material from quantitative sampling were drained through a 0.5mm sieve, rinsed by repeated gentle immersion in tap water, then emptied into a white plastic tray of dimensions 340 x 250mm, and covered with water to an approximate depth of one centimetre. Sufficient material was placed in the tray to form a fairly continuous thin cover over the base. From one to three trayfuls were needed per sample, depending on the amount of fine vegetation and detritus. Each tray-full of material was examined first under a bright fluorescent lamp using a head-mounted magnifier of 1.5x magnification. All visible organisms were removed and placed into 70% iso-propanol in Petri dishes, in groups sorted as far as was possible at this magnification. After the first sorting, the sample was agitated and re-examined. After this low-power search, successive small amounts of the remaining material were poured into an oval white ceramic dish and examined under the low powers (10x) of a binocular microscope; any small organisms missed by the earlier search were removed and added to the sorted material. Sorted material in Petri dishes was then identified and counted.

4.2.6 Limitations of the sampling methodology

Sample sizes are necessarily small because the selected method is intended to be reasonably unintensive. The aim was to gather a sample of adequate but not damaging size from a short sampling stretch and to be operable without wading into the water to avoid affecting the stonewort recolonisation.

Even before management many species were present in the samples only at low density; this is certainly and generally true of many water beetles. As a result of the low density and small sample size, the quantitative samples may contain a rather limited proportion of the pond's fauna and very small numbers of the more important species. It is apparent from the numbers captured that the inventory samples in this survey, though intended to be exhaustive, almost certainly were not.

4.3 Great Crested Newts

Surveys conducted by trained staff and volunteers consisted of a visual night time search using a CLUBMAN 500,000 candle power torch. Each survey began about 30 minutes after sunset, as soon as it was dark. The surveyor walked slowly along the bank, continuously scanning the water and vegetation fringes with the torch beam. Due to a presumed higher detectability in managed areas, where vegetation cover was reduced or absent, the whole pond was surveyed without separating out the fifteen metre stretches.

Species, sex, age-class, courtship behaviour, egg laying and egg presence were recorded for all amphibians, although the abundance of great crested newts is the most important metric. Data on the following environmental variables were also recorded: air temperature, rainfall/ripples on the pond, water turbidity, vegetation cover, cloud cover, wind speed and wind direction. In addition surveyors noted presence/presumed absence of fish and wildfowl, in order to account for their potential effect on newts, but there was no evidence of either in any of the ponds surveyed.

Torching was selected as the least invasive newt survey methodology from which abundance values can be generated, but there are recognised issues related to variability of detection rates.

1. Detectability of newts varies between ponds, with increased vegetation and turbidity making newts less detectable. Water was especially turbid in completely cleared and new ponds until late spring 2009 and again in early 2010; by contrast turbidity was lower in partially cleared ponds and control ponds, but vegetation cover was correspondingly higher. These two factors should not be considered to cancel each other out, but should be borne in mind when interpreting the results.
2. The number of newts observed is always highly dependent on weather and time of year; detectability therefore differs between survey events. Where possible surveys were carried out under appropriate conditions, but exact conditions cannot be replicated.

Surveys are therefore repeated throughout the peak season to minimise the risk of weather-influenced outliers biasing the results. Differences between these survey events should not be taken as indicative of changing abundance throughout the season, due to the variation in detectability; instead, the data should be used to generate a peak newt count for the survey season.

4.3.1 Timetable of work

All ponds within the four clusters were visited seven times in 2009 and three times in 2010. The optimum survey period was missed in 2008 due to the late start of the project, so data from a single survey of each pond in 2006 was used as a surrogate baseline. The exception was pond R13 in Cluster 1 (complete clearance), which was surveyed four times in 2006; peak count data has been used for this pond.

The table below summarises the timetable of sampling.

Sample period	Date of survey
Spring 2009	1 April
	8 April
	29 April
	5 May
	11 May
	20 May
	10 June
Sping 2010	29 March
	27 April
	12 May

4.4 WATER VOLES

A visual daytime search was undertaken. The surveyor walked around the edge of each pond scanning the water and vegetation fringe, up to two meters from the waters edge, for key signs of water vole presence, specifically feeding signs and stations, droppings and latrines, footprints and tunnels. To ensure that signs were recent presence was confirmed only when fresh (green) feeding stations or latrines/droppings were found.

These surveys solely aim to show presence/likely absence. While there is a formula for estimating abundance from field signs, it is calibrated for a very different habitat and is not of use for Hampton Nature Reserve (Morris *et al.*, 1998).

Following the initial pre-management survey in autumn 2008, three visits were performed in spring and autumn 2009 and one in spring 2010. Water voles are not very active above ground over winter and vegetation cover is at its peak over summer reducing detectability, so surveys were avoided at these times.

4.4.1 Timetable of work

The table below summarises the timetable of sampling.

Sample period	Date of survey
Baseline survey Autumn 2008	1 November
Spring 2009	10 June
Autumn 2009	1 September
	14 October
Spring 2010	24 March

4.5 WATER AND SEDIMENT QUALITY

4.5.1 Water sampling methods

The chemical properties (total conductivity, pH, redox, nitrate, phosphate and total copper) of the pond waters and sediments were monitored before and during the restoration processes. The timing of the records coincided with monitoring of other habitat variables. The following variables were measured:

Interstitial water pH*
The pH of the water in the top 2cm of sediment was recorded using a calibrated* HANNA H31N field pH meter and glass electrode.

Water Eh (redox) potential (mV)
The electrode potential of the water was recorded using a calibrated* HANNA HI8014 hand meter with a platinum/gold electrode.

Interstitial water Eh* (redox) potential (mV)
The Eh of the water in the top 2cm of the sediment was recorded using a calibrated* HANNA HI8014 hand meter with a platinum/gold electrode.

*Field Eh readings used for comparative statistics were corrected by 59 mV per unit pH to values for a standard Hydrogen electrode at pH 7 to give an Eh_7 by the formula E_7 = Field mV +[(Field pH - 7) x 59]: True Eh_7 was then calculated by addition of 204 mV to tabulated and figured values.

Open and interstitial† water conductivity (μScm-1) was recorded using a calibrated* HANNA H1993310 field hand meter.

†The conductivity of the water in the top 2cm of sediment (μScm-1).

Field meters were calibrated using HANNA standard calibration solutions at 20oC, using a glass bulb thermometer and HANNA standard solutions (pH 4 & pH 7, Eh_7 at 250mV). The electrodes were washed in reverse osmosis water and tissue dried prior to calibration. The operation was carried out in a motor vehicle at 8 am each day, with the calibration solutions being heated to 20oC using the internal heater of the car and the windscreen de-mist vents, or in warm weather cooled in the cool box. During surveys electrodes were re-calibrated if extreme values were recorded in order to check for erroneous meter reads.

Water samples were collected in 25ml virgin high density (linear) polyethylene (HPDE) scintillation vials (Perkin Elmer USA). At each water body three singular 25ml samples were taken at each of three sections of each pond by opening an acid washed 25ml glass vial or scintillation vials at 10 cm depth. The three samples were mixed in a 250ml glass beaker previously rinsed with 0.5M acetic acid and Milli-Q water. A single 25ml sample was taken from the pooled sample using acetic acid washed 50ml polyethylene syringes. The samples were filtered through a 2μm Satori filter to remove particulates and algae and each stored in a new 25ml scintillation vial. Samples were placed in a lidded Coolmatic™ 49 L mobile compressor fridge/freezer and stored at -5oC for laboratory analysis. Samples were defrosted for one hour in the laboratory at room temperature (18-22oC and analyzed for anions and cations within 1hr).

4.5.2 Water sample analysis methods

Dissolved anions

A Dionex DX100™ packed column HPLC was calibrated for detection of NO_3^-, PO_4^{---} using Dionex™, standard reagents of $100mgl^{-1}$ and Milli Q water. Limits of detection were extrapolated via linear coefficients at, NO_3^-, $26\mu gl^{-1}$ ($5.9\mu gl^{-1}$ N) r^2 0.994, PO_4^{---}, $17.8\mu gl^{-1}$ ($5.8\mu gl^{-1}$ P) r_2 0.993, SO_4^{---}. Quantitative analysis for the ions was carried out by packed column HPLC (Dionex100™) using 0.2M Dionex™ bicarbonate elluent at a flow rate of 90 $\mu lmin^{-1}$.

Dissolved copper
Determination for elemental, Cu, was by Inductively Coupled Plasma Atomic Emission Spectroscopy (Plasma phase Varian Vista-Pro ICP-AES) (ICP). 1ml of each sample diluted 1:10 with Milli Q water and subsequently acidified for ion dissociation at 20% i.e. 0.2ml 5M HNO_3, + 0.8ml sample. Limits of detection for the standard were extrapolated to 1ppb.

4.5.3 Timetable of work
The table below summarises the timetable of sampling all ponds.

Sample period	Date of survey
Baseline survey Autumn 2008	10 October
Spring 2009	29 April
Summer 2009	5 September
Autumn 2009	17 October
Spring 2010	21 April

4.6 Multivariate Analysis

4.6.1 Introduction
Principal components analysis (PCA) is a statistical method of examining data where many variables or field records are combined in order to look for associations within the data. It is a valuable tool for seeing which components of measured variables tend to associate with each other. It is very important to recognise the limits of such analysis, in that it does not imply or 'prove' causal or dependent relationships. When correctly used it does however flag up important factors within the data that are either closely or in no way closely associated. The analysis is based upon vector and matrix mathematics of the correlation co-efficients within and between co-correlated data. It expresses the interplay between variables when many variables correlate with each other at the same time, for example daylight, oxygen concentrations in the atmosphere, growth rate of plants and temperature. The mathematics of the analysis work out a significance of the model produced expressed as a 'significance' or 'P' value, which is the probability that the result of the analysis is a random event. The lower the 'P' value the more reliable the model of associations. Statisticians commonly look for a 'P' value of less than 0.05 (5%) or 0.01 (1%) to qualify a model. For example $P<0.01$ means that if the experiment or data were repeated or collected 100 further times on only one occasion (1%) would the result be likely to be significantly different from the original result and hence is valid 99/100 times. Or put another way, the chance of making a mistake by believing the model would be less than 1%.

4.6.2 Methods
A Principal Components Factor Analysis (PCA) of charophyte, newt, water vole and water quality data was conducted using SPSS © statistical analysis program (© IBM). Invertebrate and non-stonewort plants were excluded from the analysis not only because of the incompatibility of various data collection and reporting methods, but also the enormous volumes of data collected, and because the key focus of the project was to inform restoration for Chara canescens.

Where possible, data were collated as continuous numerical or logistic data (presence [1] or absence [0]). Data recorded as DAFOR was translated into categorical scores of 0-5, where 0 = absent, 1= rare, 2 = occasional, 3 = frequent, 4 = abundant, 5 = dominant.

Data entered for *Chara canescens* were percentage cover, and a separate variable representing the sum cover of all charophytes, inclusive of *Tolypella sp.* at a sample station, was created as 'Total Chara'. Total count data for both great crested and smooth newts were included and further divided into categories of adult and larvae. Water vole data were presence/absence and entered as a 1 or a 0. Water chemistry values were all numerical continuous.

Management methods were entered into the datasheet as a 1 or 0 for each method, i.e. either present or absent, and each management method was entered as a separate but equally weighted variable.

Three ponds were included in the analysis for each of control, partial manual clearance, partial mechanical clearance and complete clearance management methods. Two newly dug ponds were included, one being part of a cluster of ten new ponds dug away from the main lines of original ponds and one being within the most northern section of 'R' labelled ponds on the site map.

The algebra of the PCA was restricted to expressing the two highest ranking components of association to remove weak associations and an illustration of the correlations between measured variables which were expressed as 'component scores' and plotted in one dimension (Figure 21). Further explanations of PCA methods and principles can be found in Sokal and Rohlf (1995), Tabachnick and Fidell (2001), and Fowler *et al*. (1995).

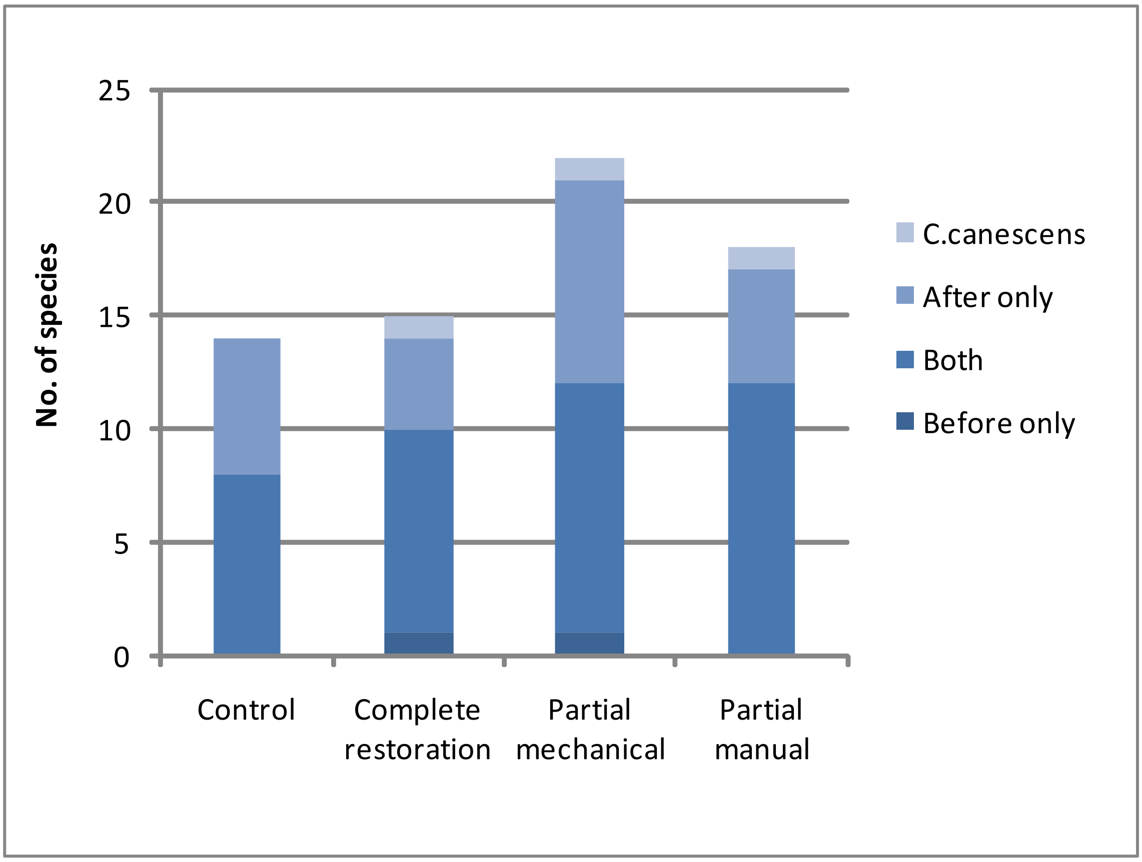


Figure 11. **Occurrence of aquatic species (including stoneworts) before and after works**

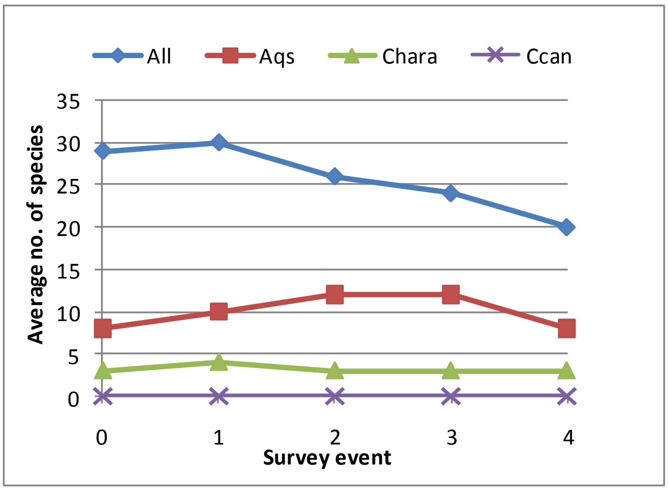


Figure 12. **Species richness in different guilds recorded in control ponds** (data for whole pond)

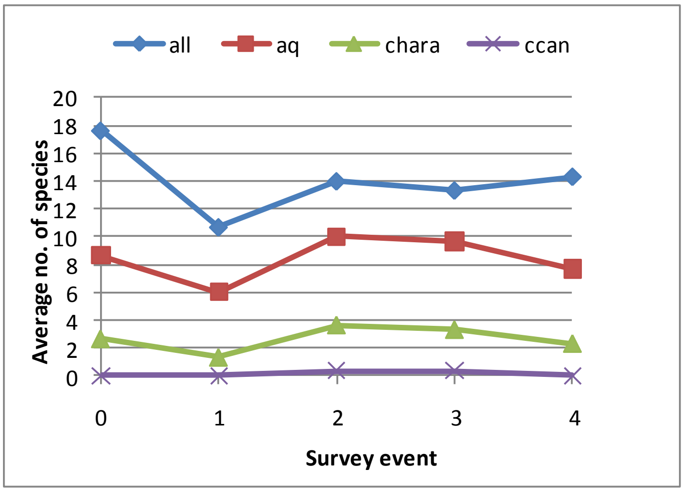


Figure 13. **Plant species richness in different guilds recorded in ponds with partial manual restoration** (data for whole pond)

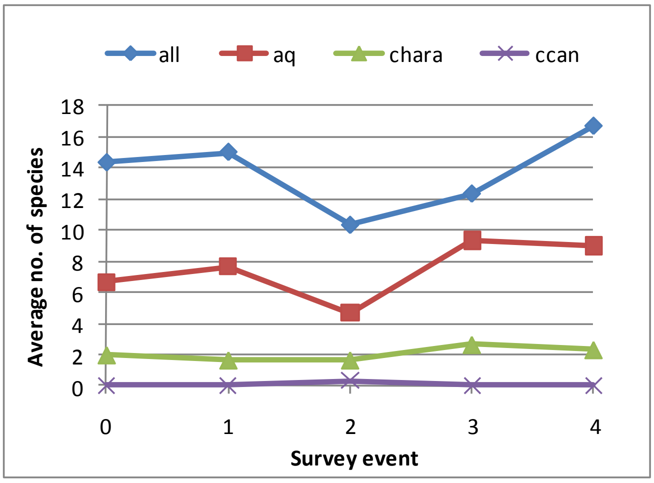


Figure 14. **Plant species richness in different guilds recorded in ponds with partial mechanical restoration** (data for whole pond)

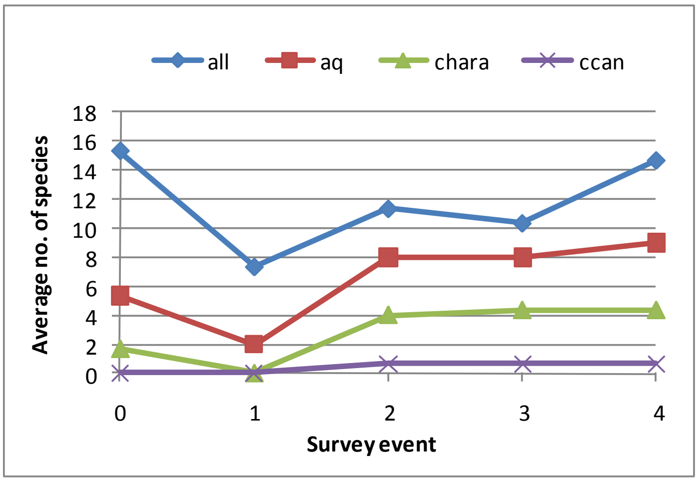


Figure 15. **Plant species richness in different guilds recorded in completely restored ponds** (data for whole pond)

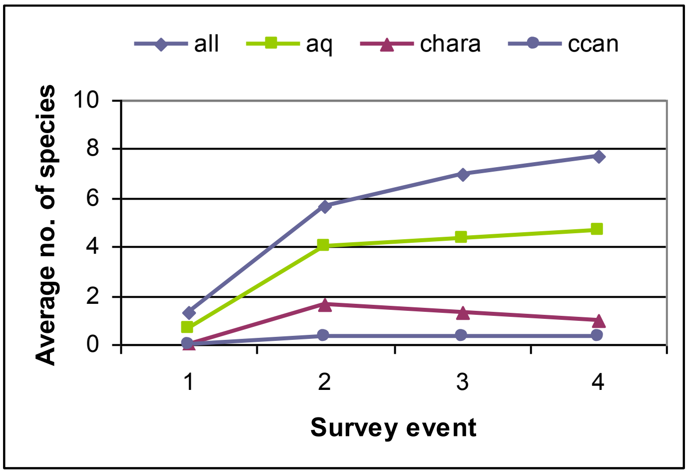


Figure 16. **Plant species richness in different guilds recorded in new ponds** (data for whole pond)

Volunteer work on pond 29A

Work finished on Pond 29A

5. Results and Analysis

5.1 Stoneworts and aquatic plants

63 species of plant were recorded across all five surveys. 24 of these species are defined as aquatic (see Table 3.), including seven of the ten stoneworts known from the site and the category FGA (unidentified filamentous green alga). The definition of aquatic may be taken in this context to be that the plant either lives completely in water or can tolerate its roots being submerged for at least 50% of the time. For reference purposes, the list of species included in Aquatic Plants of Britain and Ireland (Preston & Croft, 2001) can be taken as a starting point, together with the stoneworts (all of which are aquatic) and identifiable algae found in contact with the water. Some mosses are also recorded as aquatic plants, although there is no widely recognised UK list of aquatic bryophytes; in this case the species listed are those consistently seen elsewhere in an aquatic habitat.

Table 3. **List of aquatic plants recorded** (as defined in the text above).

Scientific name	Group
Chara aculeolata	Stonewort
Chara aspera	Stonewort
Chara canescens	Stonewort
Chara hispida	Stonewort
Chara virgata	Stonewort
Chara vulgaris	Stonewort
Tolypella glomerata	Stonewort
Cladophora glomerata	Other alga
FGA	Unidentified algae
Gongrosira sp.	Other alga
Calliergonella cuspidata	Moss
Drepanocladus aduncus	Moss
Fontinalis antipyretica	Moss
Leptodictyon riparium	Moss
Alisma plantago-aquatica	Vascular Plant
Eleocharis palustris	Vascular Plant
Lemna trisulca	Vascular Plant
Phragmites australis	Vascular Plant
Potamogeton coloratus	Vascular Plant
Potamogeton natans	Vascular Plant
Potamogeton pectinatus	Vascular Plant
Ranunculus trichophyllus	Vascular Plant
Schoenoplectus lacustris	Vascular Plant
Schoenoplectus tabernaemontani	Vascular Plant

The data, observations and hypotheses noted in this section have not been subjected to statistical analysis, and therefore indicate generally observed trends rather than statistically robust proven changes in species richness of community assemblage.

5.1.1 Vegetation composition

Figure 11 below shows, for each management technique, the number of aquatic species recorded only before management (i.e. losses), only after management (i.e. gains) and the number recorded both before and after management. New ponds are excluded because there was no pond to survey before works.

There is no permanent loss of aquatic species across the ponds cleared partly by hand, while the loss to ponds cleared either partly or completely by machine is confined to two algal taxa, one an unidentified filamentous green alga and the other an unobtrusive epiphyte which may have been overlooked. It therefore appears that pond restoration, even complete mechanical restoration, does not have a negative impact on plants, even later succession species, despite the initial dip in species richness immediately following management.

It is equally apparent that the control ponds acquire new species in about the same proportion as the managed ponds, illustrating the dynamism of the pond vegetation and the effect of seasonality on survey returns.

5.1.2 Species richness within guilds in control ponds

The surveys were intended to reveal changes in flora as a consequence of the management work undertaken. In this respect the numbers of species observed in various guilds are the most telling statistics: all species combined, amongst the aquatic plants only (including stoneworts), amongst the stoneworts (including *C. canescens*), and the occurrence of *Chara canescens*.

The number of species observed is affected by a range of other factors, such as recorder error, seasonality, weather conditions, water turbidity and water levels. The degree of variation in the numbers of species recorded due to such factors is indicated by data from the control ponds (Figure 12).

The apparent decline in the total number of species highlights the problems associated with recording plants in ponds. Notably, this decline is not matched by the figures for aquatic plants only, although there is variation in aquatic plant diversity. Taking seasonal variation into account, the number of aquatic plant species tends to increase at the expense of terrestrial species; this indicates a decline in water levels as a) the recording area falls below the tolerance of some terrestrial species, and b) more aquatic plants can be recorded due to smaller pond dimensions and shallower waters. So these findings may be an artefact of the recording method. The numbers of stonewort species remained fairly stable, and it is of note that *Chara canescens* was not recorded at all in the control ponds, which becomes more significant when one notes that *C. canescens* was not recorded in any pond in the first survey (before management had been undertaken).

5.1.3 Broad differences between management effects on plant assemblages

A decline in species richness across all guilds would be expected following all three management techniques because plant material is removed; this decline should be most marked following complete restoration where the greatest volume of material is removed. This pattern was observed, although the effect was delayed under partial mechanical clearance (Figure 14); the reason for this delay is unclear. This dip was not observed in the control ponds and as such the effect can be assigned to management.

Subsequent to this dip there is a large increase in species richness across all guilds under all three management regimes; this rise is also seen in the new ponds and is to be expected as newly-cleared areas become colonised. Whilst there was a corresponding increase in species richness in the control ponds, showing the effect of seasonality or changes in detectability, these gains were subsequently lost from the control ponds by the final survey event. This pattern was also observed in the ponds with partial manual restoration, indicating that the effects of this management technique on the plant community are negligible.

By contrast the mechanically restored ponds all ended the survey period with a higher species richness than in the initial survey, indicating true colonisation events and a rejuvenating effect rather than simply the effects of seasonality. In ponds with partial mechanical restoration this increase appears to level out by the final survey, but in both completely cleared and newly dug ponds the initial increase in aquatic species richness continues throughout the survey period, albeit at a reducing rate, compared to the decreases observed in the control ponds. This suggests that, in contrast to partial clearance, the recovery period after large-scale clearance and pond creation is longer and that it may create a greater and more diverse set of opportunities for colonising species and for species-rich early succession communities. The increase of all guilds combined is accounted for largely by the invasion of weedy ruderals of the terrestrial guild.

Limitations

The average number of species does not exceed 10 in any of the treatment groups; variation is therefore within a very small range so stochastic changes to species assemblages will have disproportionate effects. Caution is therefore required when interpreting these results.

Trends require multiple data points along a timeline, but they are also very timescale dependent. Because this study period was very short we are looking at within year (i.e. seasonal) trends. By singling out the first (baseline) survey and the final survey for comparison we are able to compare an annual change, but drawing conclusions from a trend constructed from only two data points requires extreme caution.

Conclusions

The data suggests that for aquatic plants partial restoration by hand does not have any measurable effects. Partial mechanical restoration appears to increase species richness slightly, while complete restoration and new pond creation show the greatest potential for increasing aquatic plant species richness over a longer period. The effect on terrestrial species is difficult to establish due to the limitations of the survey methodology.

Further study of these ponds would be worthwhile to illuminate the long-term effectiveness of each pond restoration technique, and in the case of newly dug ponds especially (where the total number of colonising species was still very low at the end of the study) the extent to which plants of differing guilds can colonise over time.

5.1.4 Broad differences between management effects on stonewort assemblages and on colonisation by *Chara canescens*

The effect of increased species richness noted in the vegetation of managed ponds also extends to the stonewort community. Management techniques ranked from complete restoration and new pond creation (4 new species), to partial mechanical restoration (3 new species) and partial manual

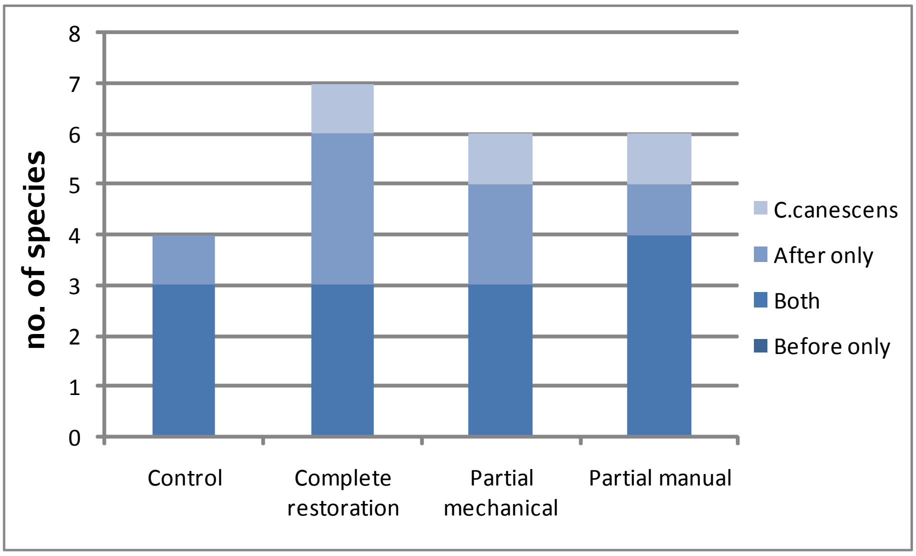


Figure 17. **Occurrence of stoneworts before and after works**

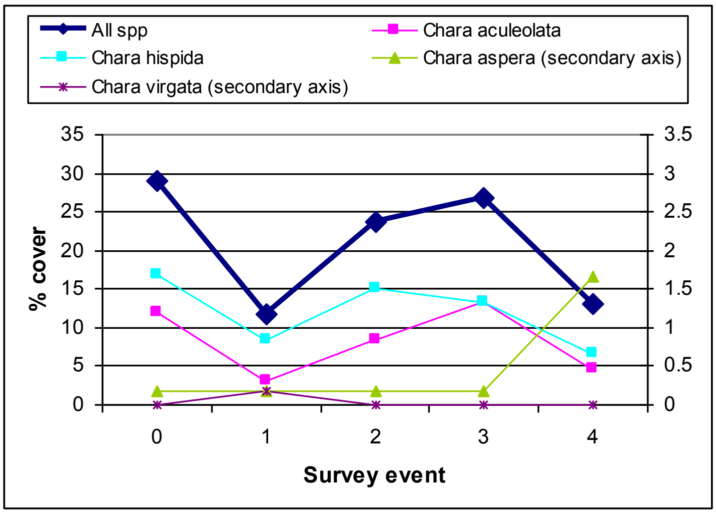


Figure 18. **Mean percentage cover of stonewort species per visit in control ponds**

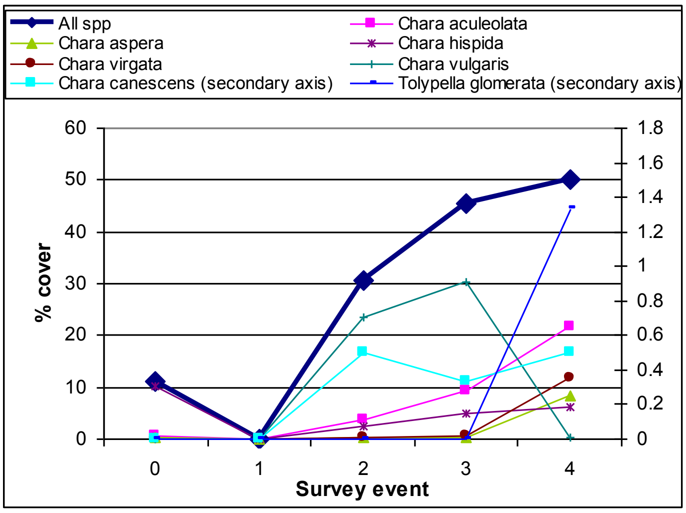


Figure 19. **Mean percentage cover of stonewort species per visit in completely restored ponds**

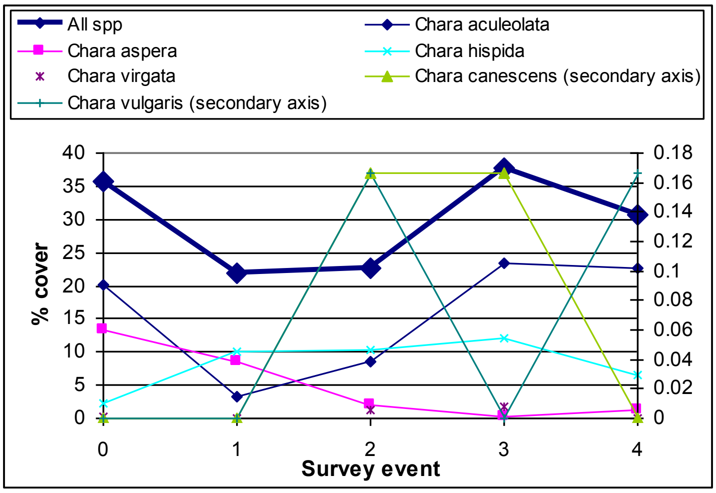


Figure 20. **Mean percentage cover of stonewort species per visit in partially manually cleared ponds**

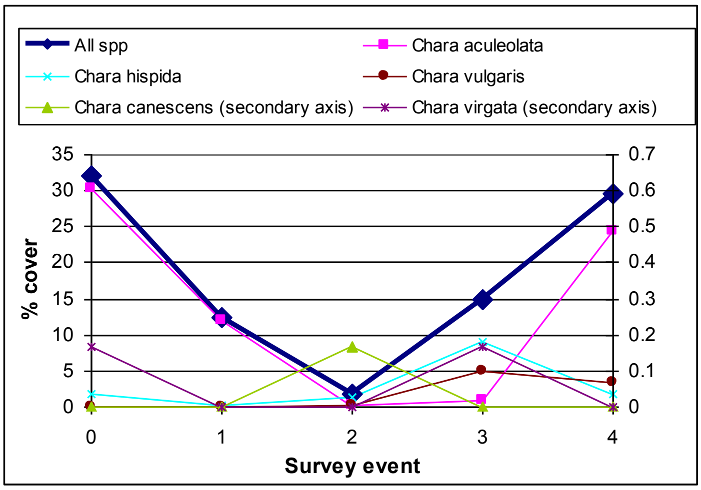


Figure 21. **Mean percentage cover of stonewort species per visit in partially mechanically cleared ponds**

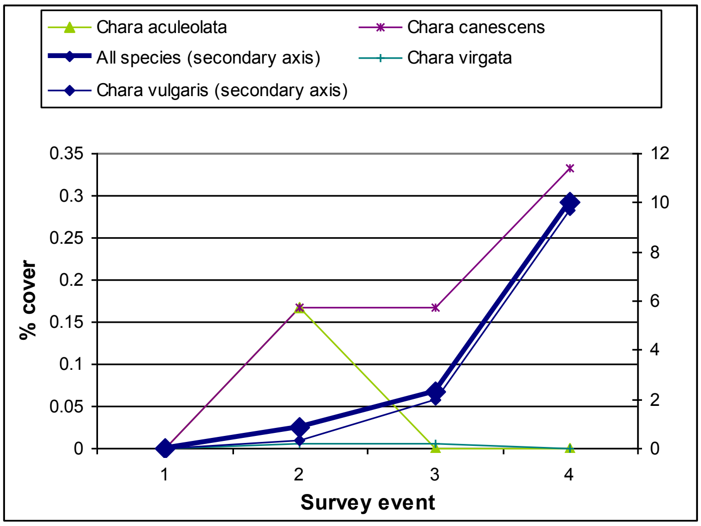


Figure 22. **Mean percentage cover of stonewort species per visit new ponds**

restoration (2 new species), compared to only one new species in the control ponds. This is perhaps unsurprising as all of the stonewort species, especially *C. canescens*, are associated with early succession habitats of the kind generated by the management options applied, especially complete clearance.

Furthermore, while no pond began the study with *Chara canescens* present, each of the management groups (including the newly dug ponds) had gained it, whilst the control ponds had not. Even though the sample size is small, the experiment demonstrates that restorative management of any type can stimulate the reappearance of *Chara canescens* in ponds believed to have supported it some decades previously.

The consistency with which *Chara canescens* grew in ponds following management is best shown by the table below. In all cases percentage cover of *Chara canescens* was both relatively and absolutely low.

Table 4. **Number of ponds with *Chara canescens* before and after works**

	Before works	After works
Control	0	0
Partial manual restoration	0	1 (in cluster 3)
Partial mechanical restoration	0	1 (in cluster 1)
Complete restoration	0	3
New pond creation	0	1 (in cluster 1)

It should be noted that while *Chara canescens* did grow in partially restored ponds it did not persist in them; this suggests that for management targeting *Chara canescens* an aggressive approach to pond restoration is more effective than partial works.

Control ponds

Figure 18 below also shows the average percentage cover of stonewort species in the control ponds; much of the variation in this graph represents the seasonality of stonewort growth, with low cover levels in early spring. Interpretation of patterns of abundance in the managed ponds should take this into account.

Note that only four species were recorded in the control ponds throughout the whole study: *Chara hispida*, *C. aculeolata*, *C. aspera* and *C. virgata*; with the former two species, both perennials, fluctuating but co-dominant throughout. The numbers of stonewort species remained fairly stable, although *C. virgata* was only detected on a single survey visit.

It is of note that *Chara canescens* was not recorded at all in the control ponds. This is significant when one notes that *C. canescens* was not recorded in any pond in the first survey, that is, before works had been undertaken.

Complete restoration

Figure 19 shows that the continued increase in aquatic species following management is accompanied by a stable stonewort community averaging 5 species, including a strong *Chara canescens* presence in all three ponds (see Table 4).

Of the three species present before restoration *Chara hispida* was dominant. Whilst the control ponds also registered a post-management decline on survey visit 1 in spring, stonewort cover was reduced to zero by the complete restoration and this is not simply due to the seasonal drop in cover values.

Succession changes can be seen in (i) the relative decline of the previously dominant of *C. hispida* following works (this is a long-lived, large, perennial species), (ii) the appearance, increase and persistence of most species subsequent to works when new substrates have been exposed, (iii) the decline of *C. vulgaris* as other species slowly increase towards the end of the survey period, and (iv) the slowing of increase in stonewort cover as a whole (although this latter point may have been due to seasonal effects and heavy rain, as total cover in the control ponds also declined at this juncture).

The increase in stonewort species richness and total percentage cover following restoration is most likely due to germination of buried spores rather than vegetative colonisation. It is also assumed that where species rapidly acquire high levels of cover (e.g. as with *Chara vulgaris*) that this is due to high oospore density in the substrate as opposed to rapid colonisation from elsewhere; from personal recollection, such high cover values were achieved by the growth of many plants rather than the vegetative expansion of a few.

Partial restoration

The effects of management were visible but less apparent in the partially restored ponds, which started with a different stonewort assemblage, where the extent of restoration was less, and where re-vegetation from non-restored areas may favour established species.

The initial drop in percentage cover cannot be so confidently ascribed to removal of vegetation as there was a corresponding springtime drop in the control ponds. However, for partial mechanical clearance this decline in the dominant species continued beyond the spring dip in the control ponds so there does appear to be a genuine post-management depression. Following this there was a corresponding increase in species richness with the appearance of new species, some of which then increased in cover and persisted, although others including *Chara canescens* did not; no such pattern was seen in the control ponds (See Figure 18).

The pattern in partial manual clearance is less clear cut; whilst none of the four stoneworts present from the start disappear completely, neither do any of the species which appear after management persist and so it does not appear that this technique has any greater or longer-term benefit for stoneworts than the control ponds.

The fairly rapid return to dominance of *Chara aculeolata* in the partially restored ponds may be partly due to the proximity to intact plants still present in the pond, compared to the suppression of the previously dominant *Chara hispida* in completely restored ponds. It may also be that sediment conditions, i.e. redox and pH, were not changed enough to promote a shift in species assemblage. This also emphasises the extended recovery period associated with works on a larger scale such as complete restoration and new pond creation, which may explain why *Chara canescens*, which has been shown to exist in tightly defined sediment redox and pH niches (Lambert 2007), has persisted only in completely restored and new ponds, where a dramatic shift in sediment interstitial climate has occurred.

New ponds

In contrast to completely restored ponds, the initial peak in species richness drops, with *Chara aculeolata* not persisting beyond survey event 2 or *Chara virgata* beyond survey event 3; it is not clear why this should be. However, throughout the survey period the percentage stonewort cover increased exponentially, representing an increase in the dominant *Chara vulgaris*.

It is of note that one of the ponds (in Cluster 1) was colonised by *Chara canescens* within a year of its creation; its percentage cover continued to increase throughout the survey period and the species was still present at the end of the study.

5.1.5 Conclusions and implications for pond management on Hampton Nature Reserve

The findings of this experiment should apply to ponds in general, but are especially relevant to ponds with a calcareous clay base like those found on Hampton Nature Reserve. With regard to plants there are three main conclusions to be drawn from this experiment:

1. *Chara canescens* can be stimulated to appear in ponds where it is not currently found, as well as in newly created ponds, by the application of physical restoration of early succession habitats. The species appears to favour complete rather than partial restoration which tallies with the perception that it is a plant found in habitats at an early succession stage. Complete restoration appears to be more beneficial than new pond creation; it is not clear why this should be, although higher oospore density in recently occupied ponds may be a factor.

2. Physical restoration of ponds stimulates stonewort species richness; this effect is most marked in completely restored ponds rather than only partially restored ponds. This suggests that stoneworts in general are adapted for the colonisation of early succession habitats. Completely restored ponds appeared to offer a better habitat for stoneworts than newly dug ponds, although the latter do create new pond habitat and both were continuing to be colonised at the completion of this project so a longer timescale is needed to confirm this. As with *C. canescens*, it is likely that new appearances at restored ponds are derived from dormant oospore reserves in the substrate rather than colonisation from elsewhere, although this is not proven. Viable oospore have been shown to be carried from pond to pond in bird guts (Proctor, 1962), and this might also be the case in new ponds as birds colonise fresh habitat.

3. Partial manual clearance does not appear to influence aquatic plant species richness, but the more thorough mechanical restoration does, with the greatest impact derived from complete restoration. This is most likely because the aquatic plants found are generally perennial; complete mechanical restoration removes roots and other living plant material upon which perennial plants rely to regenerate, while annuals rely on seeds and spores, some of which may be expected to remain in the substrate. Having said that, many aquatic perennials, such as the notable fen pondweed Potamogeton coloratus, can function as annuals and appear also to contribute to the seedbank; in addition they reproduce by vegetative fragment and appear to be able to disperse in this form too, using animal vectors.

Management to benefit the aquatic flora of ponds must therefore strike a balance between the interests of annuals and perennials. This balance should favour a more aggressive approach to restoration at Hampton Nature Reserve because a) the dominant interest is in the annual stonewort community, particularly *Chara canescens*, and b) such an approach favours the majority of aquatic vascular plants. While some perennial aquatics may be disadvantaged by aggressive management, their interest may be served by maintaining a long rotation of management across the site as a whole. This is a safe approach because the site is not known to support any priority vascular aquatics; however, to ensure that no priority species are present or that a notable population of plants will not be adversely affected, it should be a matter of routine to take an inventory of the aquatics present in a pond before management is undertaken.

5.2 Invertebrates

5.2.1 Character of the pond fauna prior to management

The recorded fauna has largely the features expected of ponds in Hampton Nature Reserve, characterised especially by an absence of leeches; a very restricted range and low density of gastropod molluscs; and a high diversity of water beetles and water bugs, with a good representation of local and rare species. Overall, they support somewhat more than 50% of the aquatic species in general, and of water beetles in particular, known from the reserve as a whole. For a detailed list see Appendix 1 online. The quality of the fauna in each of the ponds is sufficiently high to qualify it as a priority pond under the Habitat Action Plan for ponds, on grounds of both overall diversity and representation of scarce species.

Though the ponds are all broadly similar in general characteristics, there is considerable variation: 23 taxa were caught only once; 68 were found in less than half the samples; and only 25 in every sample (and this includes a number of taxa so common and widely distributed that almost any pond capable of supporting significant life would be expected to contain them). The richest pond supports almost 54% more recorded taxa than the poorest. The differences between ponds may be somewhat less than these figures suggest: in particular, the inventory samples are likely to miss some species which are present at low density; it is probably impossible to generate a complete list of invertebrates from any pond and leave that pond in an acceptable condition at the end of sampling.

It is surprising to find that the richest fauna is recorded from pond R12, since this pond was sufficiently heavily invaded by reed that it would seem at first sight that the fauna should be in decline. There is an element of truth in this first impression, in that recorded interest was patchy, with species associated with open conditions largely restricted to small areas with lighter reed cover; a less rich fauna was recorded from the superficially similar R13, with more continuous and uniform reed cover. However, it is also the case that species characteristic of ponds with heavy build-up of organic debris (water beetles of the genus Cercyon, for example), were generally not recorded. Thus, none of the ponds prior to management supported anything which could be described as a late-succession fauna. Even the most heavily vegetated ponds were probably close to the mid-succession peak of their invertebrate diversity.

5.2.2 Records after management

A very simplified summary of invertebrate records is included as Appendix 2 online. Each pond is treated as a single unit, with records from the three separately sampled sections amalgamated; and species are recorded by simple presence or absence, not by counts. The absence of numbers of individuals removes some of the most conspicuous post management changes, but these are for the most part unsurprising: numbers were very low in the immediate aftermath of management, and for most species remained so throughout the duration of the study; declines were most apparent in species with the highest counts beforehand; a few taxa, such as the mayfly Cloeon simile and the planktonic larvae of the phantom midge Chaoborus, have increased to substantial populations in at least some managed ponds and areas. However, the most numerous species, both before and after management, are generally unimportant from a conservation viewpoint, and changes generally merely confirm what is visually obvious. Many species, especially of water beetles, were caught only in small numbers even in ponds where there is little doubt that they are well-established residents. In general, it is more important that species are present in a pond than that their populations are high. There are unquestionably cases where the numbers would paint a more complete picture (the detritus-feeding Asellus aquaticus, for example, present in large numbers before management, was unsurprisingly almost absent from ponds following removal of detritus, even by the second year, but occasional individuals turned up).

Appendix 3 (online) also sums records for all three ponds managed by each method. This undoubtedly loses some significant information: the differences between ponds are sufficient that there can be little doubt that the only way fully to understand the data is to examine each pond entirely separately. This, however, would confuse any broad trends with a plethora of details. For current purposes, it is considered better to wilfully avoid the detail in the interests of developing a simple picture.

Two columns of figures are given for 2009 records: those from the autumn sampling period, and those for the year as a whole, summed over all three samples. The autumn sample is the only one which is directly comparable with the baseline survey in autumn 2009: the first sample in the spring after management recorded essentially the loss of the previous fauna and the first arrivals of strays and potential colonists, before most species would have been able to establish breeding populations; mid-summer samples of aquatic invertebrates tend to be incomplete and misleading for important major groups; and since a large proportion of aquatic invertebrates have a single generation per year, amalgamation into a single set of records makes logical sense. The amalgamated list should be a reasonably complete list of the species established in or regularly visiting the managed stretches over the course of the year; the autumn sample is the one which should, logically, be the most appropriate for comparative purposes. It is unfortunate that only a spring sample is available for 2010. The timing of the sample matters less than in 2009: invertebrates have had time to colonise, and the ponds to settle; spring and autumn samples of aquatic invertebrates from ponds are almost interchangeable, and spring samples are, if anything, more reliable because, provided there has been reasonable winter rainfall, they are less influenced by drying out. However, in these early stages of colonisation, a further summer to establish breeding populations could have made a difference.

Appendix 3 includes formal statuses for all species that possess them. A second estimate of conservation significance has been made for all species, which takes into account their local status. This estimate has been made on a six-point scale, and is an informed subjective opinion rather than one based on defined criteria. Different opinions might produce somewhat different scores, but it is hoped that they would not be so different as to affect the broad thrust of the results obtained. By assigning a score to each point on the scale, it is possible to sum the individual scores to produce an overall interest score for each management group. Common and slightly local species are scored zero; scarcer species are scored from 1 (the least scarce) to 5 (the most scarce).

Three overall measures of the fauna are given for each pond group: the average number of taxa per pond; the number of species with formal conservation status recorded; and the summed interest score (see Appendix 3). By scoring common species at zero, this system divorces to a reasonable extent conservation interest deriving from scarcity from simple diversity.

As far as can be judged from these data, in 2008 prior to management the sample stretches of the ponds appear to have contained approximately 84% of the fauna of the entire pond as a whole and to be essentially typical of the whole.

Samples from 2009 and 2010 add 27 taxa which had unambiguously not been recorded in 2008 (ignoring larvae and nymphs not identifiable to species and which could belong to species previously recorded as adults, and species identified as adults which could be the same as larvae previously recorded only to genus). A few were probably present in 2008 but missed; some may be strays or adventives; a few species are ambiguous as to category.

The distribution of species richness between control and managed ponds follows a fairly clear, if sometimes approximate, pattern: the highest figures are for the control ponds, the next highest for the manually cleared ponds, then the partially mechanically cleared ponds, the wholly cleared ponds, and finally the new ponds. This is in stark reverse to the trend in Stonewort colonisation. Figures for interest scores and representation of species with formal conservation interest are less neat: the highest figures are again for the control ponds and the lowest for the new ponds, but differences between the different methods and amounts of clearance are less consistent. Figures for species richness and interest scores increased between 2009 and 2010 for the partially cleared ponds, but not for the completely cleared or newly dug ponds.

It is a reasonable, but not provable, assumption that the higher values for richness and interest in the partly cleared ponds, especially in the first year, result in substantial measure from the straying and spreading of invertebrates from the unmanaged portion of the ponds to cleared areas in which they might not be able to successfully breed. The difference between manually and mechanically cleared ponds may be explicable by the less thorough clearance of roots from the manually cleared ponds, leading to conditions which might more rapidly provide either suitable habitat for the establishment of breeding populations of a wider range of species, or simply conditions which encourage lingering or attempted breeding by un-established strays and wanderers. Increased diversity is expected with succession change in the managed areas and ponds: the evidence, so far as it can be safely interpreted over such a short period and such limited change, suggests that the rate of succession will be more rapid in the managed areas of the partly cleared ponds.

A somewhat complicating factor in this general and simple interpretation is that the results from control ponds show a marked decline in richness and interest scores between 2008 and 2009, partially recovering in 2010. This seems to be a genuine phenomenon, rather than merely an artefact of sampling, but results from changes in only two of the ponds. Pond 26A held its values well, while those of 6A and 29B changed substantially. In both cases, the difference in the character of the fauna was sufficient to be subjectively apparent even during sampling, and was seen in both spring and autumn samples. In R6, the declines in richness and quality were accompanied by a decline of 28% in the numbers of individual invertebrates captured in autumn samples, but in 29B the catch was larger in 2009 than in 2008. There are no immediately obvious reasons for the change. In the absence of changes to the ponds or their surroundings, it is usual and logical to look for reasons such as changes in the weather, but if the cause does lie here, it is not easy to see what aspect of the weather might have been responsible, and certainly impossible to prove that it was. The fact that the change was not equally felt in all ponds diminishes the chance that weather was the cause. Whatever the cause, the fact that changes of this scale can occur between successive years in unmanaged ponds emphasizes the need for caution in interpretation of changes in the managed ponds.

It is possible to identify, with reasonable confidence, a set of 27 species (17% of the species recorded during the project) which are newly arrived as a result of management, or which have clearly benefited, as indicated by a disproportionate representation in managed areas. For a full list see Appendix 3 online. This includes three which are Nationally Scarce (almost 19% of the total recorded) and 20 which were not recorded from any of the ponds prior to management. However, they also include several very common species whose fate in individual ponds is of little concern, and others which, though of some interest, are widespread on the site and occur in more established ponds; and it needs to be borne in mind that all of the other previously recorded species have suffered or gone.

Table 5 lists those species benefiting from management and pond creation which have been assigned an interest score above zero, and lists the number of ponds in each management category from which they have been recorded.

Table 5. **Species with an interest score above zero which benefited from different types of management.**

Species	Formal status	Interest score	Number of ponds from which recorded			
			Manual part-clearance	Machine part-clearance	Machine complete clearance	New
Acilius sulcatus		1				1
Hydroglyphus geminus		1	3	2	2	3
Hygrotus confluens		1	2	3	3	3
Scarodytes halensis	NS	2	2			
Haliplus flavicollis		1		1		
Haliplus mucronatus	NS	4	1	1	2	
Haliplus obliquus		2	3	2	3	
Ochthebius pusillus	NS	4			1	
Berosus affinis		1	3	3	3	2
Bersosus signaticollis		1		1		1
Laccobius sinuatus		1	2	3	2	2
Sigara concinna		1	1			1
Sigara limitata		2	1	1		2
Libellula depressa		1				1
Number of species			**9**	**9**	**7**	**9**
Total pond records			**18**	**17**	**16**	**16**

5.2.3 General observations and possible confounding factors post-management

New ponds and managed areas of previously existing ponds generally had little fauna on the spring visit, suggesting that management had been fairly efficient in wiping the slate clean, and that little had yet colonised. There was, however, considerable variation in detail between ponds.

Throughout the period of sampling, it was noticeable that the details of pond construction and minor habitat details had a significant effect on the recorded fauna. The scale at which such features had their effect varied: differences could be apparent over as little as a metre, or could differ between two ponds over the whole of the managed (or sampled) stretch. Judged subjectively, the most significant factors affecting invertebrate numbers and diversity in managed areas appear to be:

- the presence of unmanaged vegetation elsewhere in the pond;
- the speed of re-development of vegetation after management;
- the presence of drifted plant fragments along the marginal fringe;
- the angle of slope of the pond edge.

Given this latter points, care must be taken to minimise the tendency for mechanical clearance to steepen the pond profile.
There is considerable variation between ponds in the abundance and composition of the colonising fauna in the first two years since management. The most extreme edges are unlikely ever to develop high invertebrate interest, unless the angle slumps, or until aquatic vegetation becomes dense to the water surface, or a fringe of emergent vegetation develops.

5.2.4 Conclusions and management implications

Any conclusions relevant to management which are drawn from this study must be tentative, because it has been of short duration. Some of the ponds are at such an early stage of colonisation that at least one known early succession species appears to have scarcely begun to colonise, and the rate of succession change seems likely to remain slow. Continued study, especially of completely cleared and newly dug ponds, over a period of a decade or more is ideally needed. However, several relevant observations appear firmly based.

- The invertebrate assemblages of the ponds prior to management were species-rich and included a substantial number of scarce species; by the end of the study, cleared areas and ponds were substantially less rich in species and in rarities.
- Clearance of vegetation provides opportunity for a number of species of early succession stages and open conditions, including scarce species not present in more established ponds.
- Early colonists arrive rapidly after pond management, but colonisation is generally slow.
- There is rather little evidence that wholly cleared or new ponds support species which do not also colonise ponds with partial clearance, and vice versa - though there is scope for such evidence to be found in the future.
- The rate of succession change amongst invertebrates appears greater in partially cleared ponds than in wholly cleared or newly dug ponds.
- Cleared areas in partially cleared ponds may be prone to contamination by strays from the vegetated parts of the pond; it is not clear that this is in any way significant, but it is possible that such individuals provide unwanted competition for pioneer and early succession species, which include invertebrates which are known or suspected to be poor competitors.

5.3 Great Crested Newts

5.3.1 Limitations

Torch counts are highly susceptible to environmental conditions; standard practice is therefore to make repeat surveys within each season and compare the peak results. In this study the number of survey events varied widely between years (see 4.3.1), so the peak counts are not generated from equal amounts of survey effort. While it is impossible to quantify, the baseline counts - derived mostly from a single survey visit - are likely to be under-representations of newt abundance. Apparent increases from the baseline may therefore be due to increased survey effort in 2009 and 2010, and decreases may under-represent the loss. Such artefacts should apply to both managed and control ponds, so comparisons to discern management effects are still possible. However, as the baseline surveys were carried out on different nights under different environmental conditions, and because turbidity cannot be controlled for, the potential under-representation effect is not likely to be consistent, giving rise to less robust comparisons between ponds.

Interpretation of the 2010 data presents very similar challenges because only three surveys could be carried out within the project time span, compared to the full seven in 2009; decreased counts in 2010 could therefore be due to reduced survey effort and increased counts may under-represent the gain. Conducting multiple surveys may partially mitigate this risk but the effect of uneven survey effort remains impossible to quantify. In addition, survey effort between ponds was not always equal; in 2010 pond 29B was surveyed only once which may depress its count relative to the others which were surveyed three times. As 29B is one of the control ponds against which each management group is compared this makes interpretation of the 2010 data especially difficult.

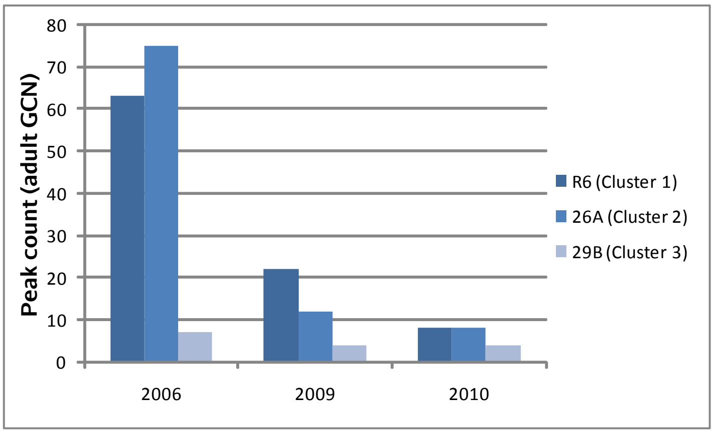


Figure 23. **Peak counts of adult GCN in control ponds**

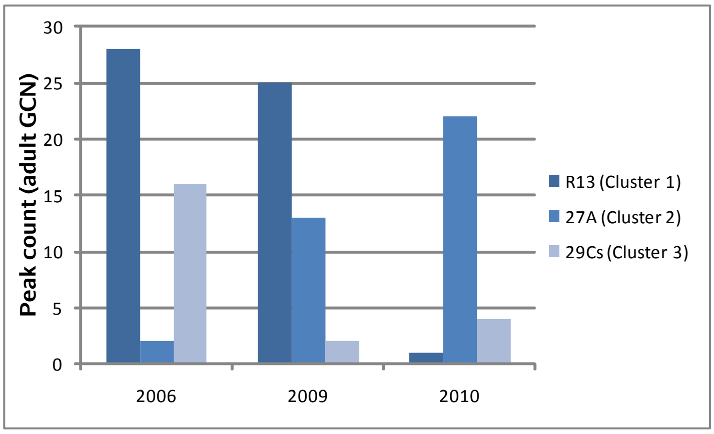


Figure 24. **Peak counts of adult GCN in completely restored ponds**

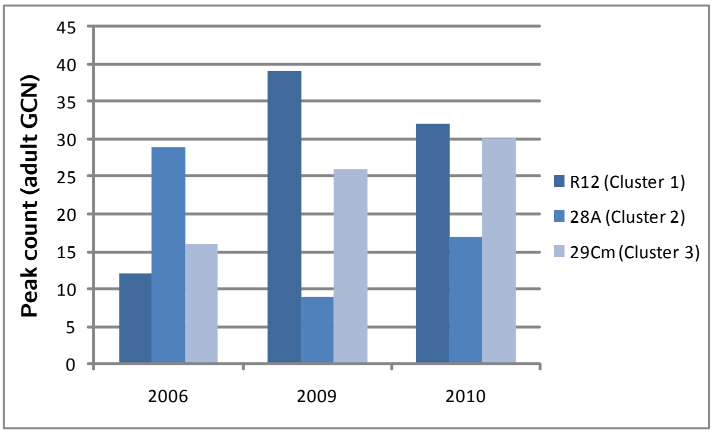


Figure 25. **Peak counts of adult GCN in partially mechanically restored ponds**

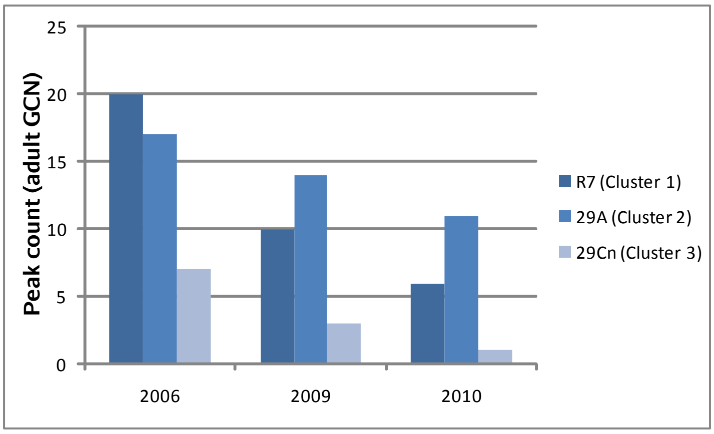


Figure 26. **Peak counts of adult GCN in partially manually restored ponds**

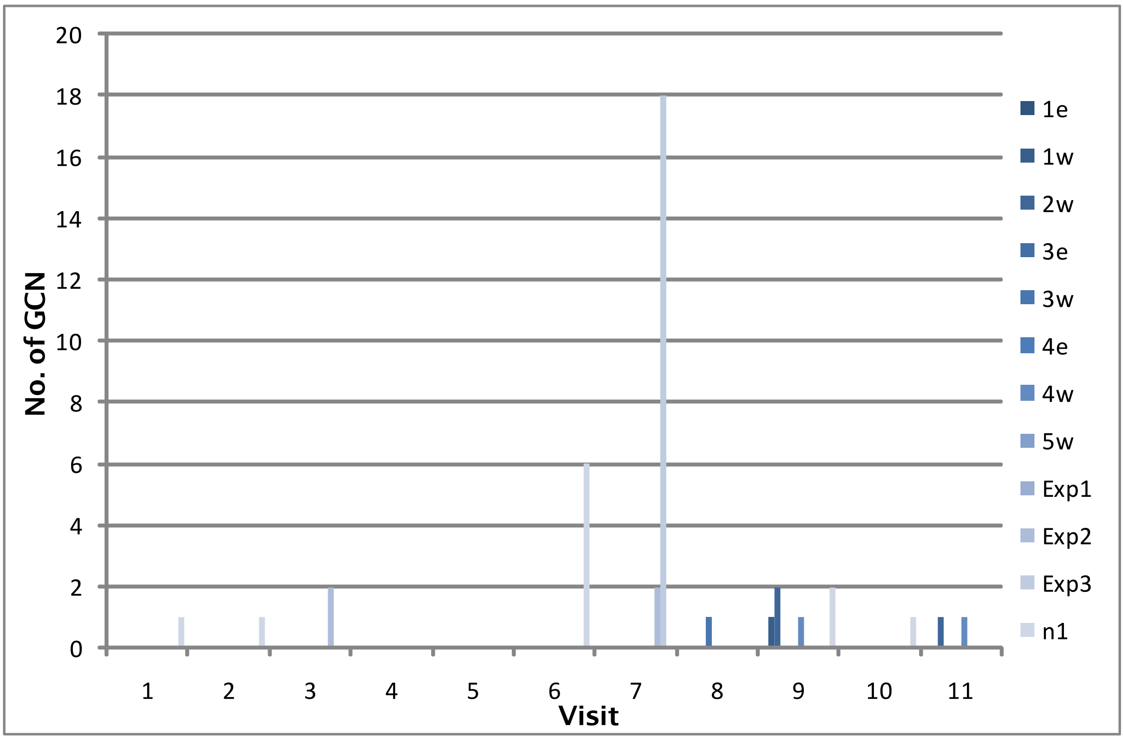


Figure 27. **GCN (n=40) in newly created ponds (n1 in Cluster 1, all others in Cluster 4). Visits 1-7 were undertaken in 2009 and 8-11 in 2010.**

All surveyors were trained and experienced herpetologists, but experience levels were inevitably not equal. Torching is a standardised, replicable methodology; by repeating the survey up to seven times the added error of using multiple surveyors is diluted. Because each year had different numbers of surveys these two factors may interact, making the results less robust.

As the ponds are not of equal size it is especially important to compare trends rather than absolute numbers. However three years is a very short timescale in which to generate or interpret trends data, even with control ponds. Results should be taken as indicative rather than definitive and continued monitoring of these ponds would be of benefit. Any conclusions drawn from this study apply specifically to Hampton Nature Reserve where the superabundance of both newts and ponds may affect the newts' response to management. For all these reasons results should be interpreted with caution, especially when translating the project findings to other sites.

5.3.2 Control ponds

Clusters 1 to 3 included a single control pond each (see Figure 23).

Management works were not undertaken in these ponds; any changes in newt abundance in 2009 and 2010 since the baseline survey in 2006 cannot therefore be due to management and must instead be attributed to other factors. The two-year gap between the baseline survey and the post-management surveys makes speculation about these factors more difficult, but on a robust site like Hampton Nature Reserve weather would be the most likely one.

By comparing trends in the managed ponds to those in the control ponds we are able to distinguish management effects from other influences on newt abundance. Peak counts in managed ponds within Cluster 3 in 2010 could be expected to be higher than those in 29B simply because they were surveyed more often, so this could not necessarily be ascribed to management techniques.

Despite only being surveyed once, ponds R6 and 26A both shared very high counts in 2006 (the highest of all ponds in any survey) and showed a similar marked decline in 2009, which continued but slowed in 2010. It is possible that had more surveys been carried out in 2010 the peak count may have been higher and the decline shown to level out, or even reverse. By contrast, pond 29B had only a very low count in 2006; this dropped slightly in 2009 and stayed low in 2010. While 2006 and 2010 could be under-representations, 2009 is certainly not.

Although we must be cautious in drawing interpretations from this data, it appears that all three control ponds follow broadly the same trend; a big decrease in 2009 followed by a reduced decrease in 2010. These changes should be viewed as baseline changes not caused by management.

5.3.3 Completely restored ponds

The three completely restored ponds (see Figure 2) all showed different peak count trends.

In Cluster 1 pond R13 decreased marginally from a peak of 28 in 2006 to 25 in 2009, and then crashed to a single newt in 2010, showing a very similar pattern to the control pond (R6). The major difference is that the control pond started with a far higher count so its initial 2006-2009 decrease was much greater. R13 is the only pond which was surveyed four times in 2006; however, the count remains lower than for the control pond and higher than the 2009 survey, despite the advantage and disadvantage respectively in survey effort - the observed patterns are therefore not artifacts of this uneven survey effort.

In Cluster 2 pond 27A rose steadily from a trough of 2 in 2006 to 13 in 2009 and again to a peak of 22 in 2010. This is in contrast to the control pond (26A) which dropped from a peak in 2006 and continued to drop in 2010.

In Cluster 3 pond 29Cs dropped dramatically from a peak of 16 in 2006 to just 2 in 2009, and then rose marginally to 4 in 2010. While the trend differs from the control pond (29B), the values match quite closely. The control pond started with a slightly lower count and so the initial decrease was less, but both 29Cs and 29B remained very low throughout 2009 and 2010.

Two of the three completely restored ponds did broadly match the control ponds, suggesting that complete restoration had minimal effect on great crested newts; the decrease observed was largely mirrored in the control ponds. Nevertheless, due to the lack of vegetation post-management the proportion of newts detected was very high, whereas prior to management detectability was lower; this may have masked a decline in newt abundance not registered in the count data.

However, one cluster did show a steady increase after complete restoration compared to a decrease in the control pond, despite a reduction in habitat quality. Contrary to claims in the literature about appropriate amounts of plant cover we observed many newts sitting on the bottom of ponds without vegetation. These mixed results suggest that other factors besides management can have a major impact on newt populations, even over-riding such dramatic interventions as complete pond restoration. The data does not offer any suggestions what these factors might be. One theory is that the superabundance of newts leads to optimum ponds reaching their maximum carrying capacity and competition forcing colonization of sub-optimal ponds.

5.3.4 Partial mechanical restoration

The three ponds partially restored mechanically also showed different peak count trends.

In Cluster 1 pond R12 increased dramatically from 12 to a peak of 39 in 2009, and then decreased marginally to 32 in 2010. By contrast the control pond (R6) showed an initial and continued fall.

In Cluster 2 pond 28A fell dramatically from a peak of 29 in 2006 to a trough of 9 in 2009, before recovering partially to 17 in 2010. The control pond mirrored this initial drastic decline in 2009 but then continued to decline marginally in 2010.

In Cluster 3 pond 29Cm increased steadily from 16 in 2006 to 26 in 2009 and again to a peak of 30 in 2010. This is in contrast to the control pond (29B) which started with lower counts, dropped marginally in 2009, and remained steady and low in 2010.

These results are a complete mix, with two ponds showing an increase from 2006, one showing a decrease, and with ups and downs along the way. It is therefore very difficult to associate changes with the management work. However, the results were higher in all these ponds in 2010 than for the control ponds, even the pond with a decrease in numbers. We might cautiously infer that this restoration technique had a positive effect on newts and has certainly not been harmful.

5.3.5 Partial manual restoration

The three ponds partially restored manually (see Figure 26) all showed the same peak count trends, which were also the same as in the control ponds.

All ponds steadily decreased from a peak in 2006 to their lowest counts in 2010 with values in line with those of the control ponds. The major difference is that the control ponds started with far higher counts so their initial 2006-2009 decrease was much greater. This strongly suggests that partial manual restoration does not have any impact on newts so, while it is not detrimental, neither does it have any of the positive effects which may be produced by partial mechanical clearance.

5.3.6 New ponds

Only Cluster 1 had a successful new pond (n1); the 10 new ponds in Cluster 4 were therefore also monitored as surrogates. All the new ponds were included in Figure 27.

The peak count in n1 was 6 in 2009 and 2 in 2010. Of the other 10 ponds one achieved a peak count of 18 once in 2009; all others peaked at 2, 1 or 0 in 2009, and at 1 or 0 in 2010. Turbidity was high but due to the lack of vegetation, as with the completely cleared ponds, the proportion of newts detected was probably very high. It therefore seems that in spite of similar conditions in completely restored and new ponds, the latter were colonised at a much slower rate, despite in both cases suitable terrestrial habitats and close proximity to already occupied ponds. This may be attributable to a quicker plant regeneration and fidelity of great crested newts in the completely restored ponds. However, all newts colonising new ponds are exploiting a completely new resource which in the longer term will increase their carrying capacity as the baseline count is always zero for new ponds; it also avoids modification of existing pond habitat.

5.3.7 Summary

In the light of the limitations referred to, care must be taken when interpreting the results of this part of the project. However, bearing this in mind, it appears from the control ponds that there is a baseline decline of newts from 2006 to 2009, continuing into 2010. While the results from complete restoration are mixed, this form of management does not appear to be causing any additional damage to newts over and above this baseline decline. The results from partial mechanical restoration are even less clear, but appear to indicate an increase in newts, at least compared to the baseline decline. The results from partial manual restoration are no different to those for the control ponds; while they do not engender the same potential benefits as partial mechanical restoration, they cause no damage. Finally, the results show that newly dug ponds will be colonised by newts, but rarely in high numbers; new ponds therefore appear to be less well suited to newts than completely cleared ponds, although they do add new habitat to the habitat pool rather than solely modifying existing habitat.

This study seems to support best practice guidelines advocating partial clearance as the most appropriate method of pond restoration targeted at great crested newts, but further suggests that this be carried out mechanically rather than manually. Results for complete restoration were mixed, but were not as damaging as expected. In the context of Hampton Nature Reserve it therefore seems that existing ponds can be restored, even fully, for the benefit of stoneworts, without impact upon great crested newts.

5.4 Water voles

The presence/absence of water vole in relation to each pond is summarised in Table 6. All control ponds were occupied by water voles; however, they were not detected during three of the five visits for Pond 29B and R6, which may be due to recorder error. This was also the case for the mechanically and manually restored ponds, which all supported water voles, but occasionally they were missed. The most significant result, as expected, was the complete disappearance of water voles from completely restored ponds, where only in the case of pond 29C(S), was any sign of water vole activity registered on the fourth visit (Table 6).

Table 6. **Presence (1) and absence (0) of water vole signs during initial and follow-up visits.**

Management	Pond	Visits				
		Initial	1	2	3	4
Control ponds	26A	1	1	1	1	1
	29B	1	0	1	1	1
	R6	0	0	1	1	1
Complete	27A	1	0	0	0	0
	29(C)S	1	0	0	0	1
	R13	1	0	0	0	1
Partial mechanical	28A	1	1	1	0	1
	29(C)M	1	1	1	1	1
	R12	1	0	1	1	0
Partial manual	29A	1	1	1	1	1
	29(C)N	1	1	1	1	1
	R7	1	0	1	0	0

Note that new ponds were excluded from this survey as both pre-and post creation the terrestrial habitat was overly exposed, poorly vegetated and not suitable for water voles.

In summary, the results of the water vole survey show that complete restoration of a pond makes the habitat unsuitable for water voles. The lack of bankside vegetation for cover and foraging opportunities would encourage the water voles to disperse to a more suitable aquatic habitat, or result in their predation. This supports the best practice guidelines that complete clearance of ponds or ditches where water voles are present should be avoided in favour of a partial clearance which leaves suitable habitat intact.

Partial clearance or no management (control) of the pond appears to be most suitable for water voles. The creation of new ponds would be likely to provide a new habitat in the long term, but not in the short term (Pond Conservation, 2010).

5.5 Water and sediment quality

There were significant differences ($P<0.05$) in water and interstitial water quality between the ponds when first monitored in October 2008. This result indicates that the experiment was not comparing 'like with like' in terms of habitat from day one. This fact makes meaningful interpretation of the variation structure of the data difficult and complex beyond the scope of this remit. However certain factors are extractable from the data.

1. Obvious significant impacts of restoration within the ponds.
2. General changes that appear to be associated with restoration activities.
3. Association of organisms with restoration techniques after 12 months of work.

Prior to any intervention the water within all ponds was found to be of neutral to alkaline pH, with a low nutrient content. Nitrates were barely detectable in any pond (max 0.04 mgl-1, min 0.01mgl-1) and phosphate were typically all below 18 μgl-1, copper was below detectable limits in all samples.

The data indicates that neither nutrient enrichment nor copper toxicity was likely to be limiting charophyte growth within the clusters according to comparison with likely limits deduced by recent research (Lambert, 2010). There were however statistically different differences in water pH, water redox, interstitial water redox, water conductivity and nitrate concentrations between clusters (Table 7 and Table 8), which means that from day one the experiments were not really comparing 'like with like' between clusters of ponds.

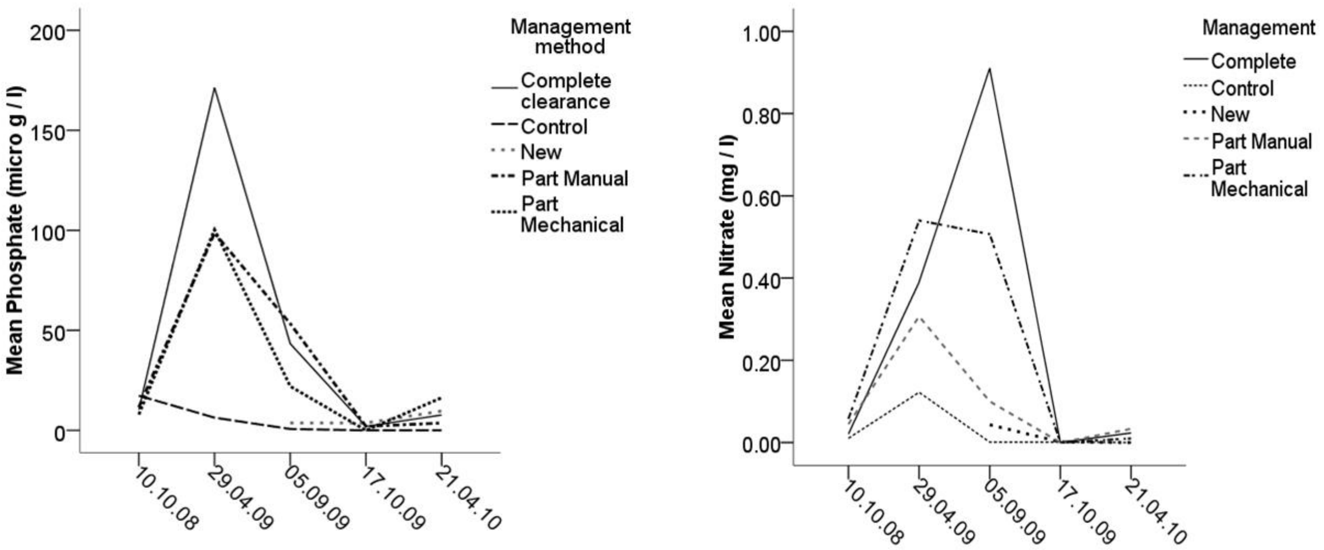


Figure 28. **Line graphs showing average (numerical mean) recorded concentrations of phosphate and nitrate within ponds subjected to different management intervention.** The control group was not managed at all; the sampling represented survey times from pre-intervention to one year post-intervention.

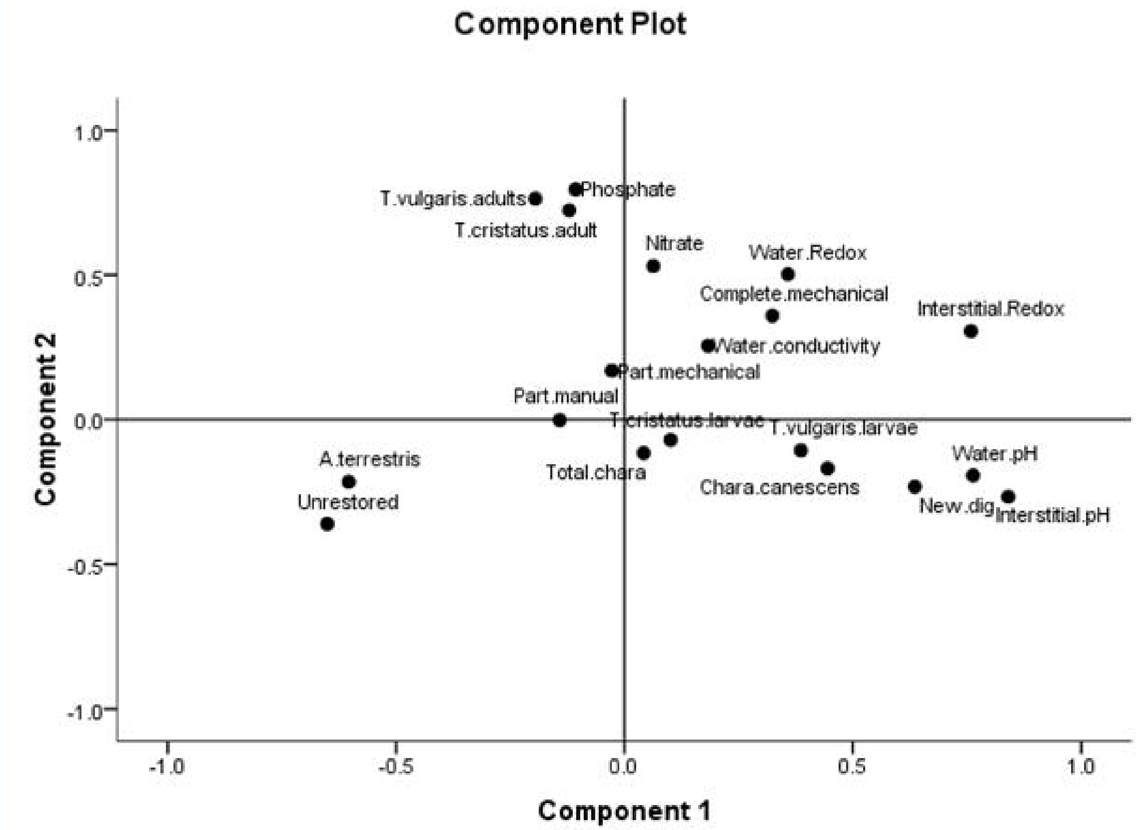


Figure 29. **Principal Components Analysis plot of the primary and secondary principal components illustrated on a singular plot.** The axis scores are unit-less as they represent mathematical 'vector scores' created by the interaction of correlations.

Table 7. **Means of grouped water chemistry variables of ponds within cluster groups prior to any intervention.**

Cluster		Water pH	Interstitial pH	Water redox	Interstitial redox	Water conductivity	Nitrate	Phosphate
1	Mean	7.5	7.4	152.1	-34.2	1242.5	0.01	7.1
	N.	12.0	12.0	12.0	12.0	12.0	12.0	12.0
	Std deviation	0.3	0.6	106.3	116.8	634.4	0.0	7.2
2	Mean	7.4	7.1	128.8	-144.8	2594.2	0.04	14.8
	N.	12.0	12.0	12.0	12.0	12.0	12.0	12.0
	Std deviation	0.2	0.4	79.9	57.9	393.7	0.0	6.0
3	Mean	7.2	7.0	62.1	-70.0	2731.2	0.03	13.5
	N.	12.0	12.0	12.0	12.0	12.0	12.0	12.0
	Std deviation	0.1	0.2	9.7	22.1	134.4	0.0	11.2

Table 8. **Critical F and significance values for a One Way Analysis of Variance to compare the mean water quality variables recorded between each cluster prior to intervention in September 2008.**

		F	Sig. (P)
Water pH	Between clusters	4.25	**0.02**
Interstitial pH	Between clusters	2.67	0.08
Water redox (mV)	Between clusters	4.29	**0.02**
Interstitial redox (mV)	Between clusters	6.57	**0.00**
Water conductivity	Between clusters	42.35	**0.00**
Nitrate	Between clusters	4.89	**0.01**
Phosphate	Between clusters	2.86	0.07

A P value less than 0.05 = a significant difference between the clusters and is highlighted in bold. Note: Figures 1 to 15 supporting the following analysis are grouped together as Appendix 4 online.

Water pH did not vary greatly within the ponds before or during restoration (Figure 1) and although there no significant increase in water pH over time within the control ponds R6, 26A, 29B (P>0.05 all cases), there was a significant increase in pH in the ponds that underwent intervention (Figure 2). A similar pattern was evident in the **interstitial water pH data**. Whilst there was no significant change in the interstitial water pH of the control ponds (Figure 3), physical intervention was associated with a general increase in the pH of the interstitial water (Figure 4).

There was a great deal of variation within and between the **water redox** of the ponds pre intervention (Figure 5); however, intervention was associated with a general drop in water redox post intervention: this phenomenon did not occur in the control ponds (Figure 6, A and B). Water redox was significantly higher in the newly created ponds (Figure 7). In the ponds where intervention took place there was a significant increase in the **interstitial water redox** post disturbance, indicating oxidation of the sediments (Figure 8). The increase was greatest in the new ponds and the mechanically completely cleared ponds (Figure 9).

Post intervention there was no significant difference in **water conductivity** in ponds that were not in the control group (Figure 10). New ponds and those completely cleared by mechanical means contained water of the highest resultant total conductivity (Figure 11). The intervention of pond clearance was quite clearly associated with increases in **dissolved organic phosphate** (Figure 12). The 24th April 2009 was the first sampling after pond intervention and following intervention concentrations of phosphate were significantly higher in restored ponds than in the control ponds (Figure 13). However, at no point did dissolved phosphate concentrations reach those likely to be critical for charophyte survival according to Lambert and Davy (2010). A similar pattern of **nitrate release** occurred immediately following intervention (Figure 14); again, however, these concentrations were well below 2.5 mgl-1 which, again following Lambert and Davy, might be considered as critically limiting to charophyte survival. **Dissolved copper** concentrations were below detectable limits (1ppb) in all samples. For the period of the trial nitrate concentrations remained elevated in ponds where intervention had taken place (Figure 15).

5.6 MULTIVARIATE ANALYSIS

5.6.1 Results

The two principal axes (components) explained 37.8 % of the total variation within the data and the model proved significant (P<0.01); they are illustrated in one dimension (Figure 21). 62.2% of the data was therefore redundant and could not be attributed to influencing the model.

In Figure 29 Component 1 can be seen to be most influenced by management methods which ranged from un-restored (control) to newly dug ponds. Component 2 related to the two measured indices of eutrophication: inorganic phosphorus (phosphate) and dissolved nitrogen (nitrate), which correlated weakly but significantly with each other, R = 0.46, P<0.01, n=207. Scores on Component 2 of 1.0 represent raised nitrate and phosphate concentrations in the open water. These raised concentrations were however not permanent, nor evident prior to the works. This increase in nitrate and phosphate can be seen to occur directly post-management, but remains relatively low and constant in the control ponds (Figure 28).

The overall impression is that the re-emergence and abundance of *Chara canescens* was most closely associated with completely cleared ponds and ones which were newly dug. The presence of water vole *Arvicola terrestris* was very closely associated with un-restored or disturbed ponds.

The completely cleared and newly dug ponds were associated with an increase in water and interstitial water pH and a re-oxidation of the interstitial water indicated by higher redox potential, all of which were in turn associated with re-emergence of *Chara canescens*.

5.6.2 Positive associations

In addition to this example, these results show the following positive associations:

- Water voles with a lack of intervention (control ponds)
- Newt larvae with partial restoration methods
- Charophytes with partially restored ponds
- Chara canescens with complete mechanical restoration, and new ponds
- Complete (and to a lesser extent, partial mechanical) restoration with temporarily increased dissolved phosphate and nitrate concentrations
- Increase in water pH, interstitial pH and interstitial redox with new ponds
- Water conductivity and redox with complete mechanical restoration

However, as important as the closeness of variables is the distance between far-off variables, which indicates a poor association.

The following were not associated:

- Water voles with new, completely, and to a lesser extent, partially cleared ponds
- Newts (especially adults) with new ponds (and control ponds)
- pH, Redox and water conductivity with control ponds

5.6.3 Discussion

The analysis shows clear association between adults of both T .cristatus and T.vulgaris which are most likely to be found in the same niche, whereas larvae of both species were associated with charophytes generally. The reasons for these association are not extractable from the model but one hypothesis may be that adult of both species are swift to breed in the managed ponds but retreated back to the shelter of the partially intervened ponds, and the fact that larvae of both species associated with charophyte vegetation may indicate greater juvenile survival in those ponds or just that they were easier to record in totally cleared ponds. Whilst this concurs with predictions from earlier studies (Lambert, 2007), the higher total percentage cover of charophytes was more closely associated with partial clearance, which may also be attributed to re-growth and vegetative population expansion from remnant rhizoids and plant fragments. However the re-emergence of Chara canescens was most definitely most closely associated with total mechanical clearance and newly dug ponds. This suggests that the plants emerged from the oospore reserves buried in the sediments.

Complete and partial mechanical pond restoration techniques are associated with nutrient release. Control ponds, new ponds and to a lesser extent manual partially restored ponds disassociate with ponds where nitrate and phosphate concentrations were relatively higher.

Any association or dissociation with nutrient levels and species may be an artefact of their association with particular management techniques, and vice-versa. For example, water vole disassociation with eutrophic ponds may be better explained by their association with the control ponds, which themselves disassociate with high nutrient values, rather than by any inherent incompatibility with high nutrients.

The strong association of great crested newts with partially restored ponds supports the advice given in Langton *et al*. (2001) for this gentler approach to management. The association of adult newts with more ponds where management was more severe is less directly understandable, but may be a consequence of increased vegetation cover following nutrient release. Why newt larvae are not associated with high level management intervention is not clear. The association of water voles with the un-restored control ponds may be better understood as a complete disassociation with new and completely restored ponds, given that water vole presence in partially restored ponds was strong. A recent study at the University of East Anglia (Lambert & Guilliat, 2011) has shown that vegetation cover and height, and the permanent presence of water, are critical to habitat selection by *A. terrestris*.

Water vole (photograph: Sue North)

Great crested newt

6. Cost-effectiveness of pond restoration methods

6.1 Issues

In this report the cost-effectiveness relationship explores two main choices: volunteer (manual) vs. mechanical (contractor) restoration, and partial mechanical vs. complete mechanical restoration. Cost-effectiveness with regard to pond creation, and in particular restoration, is both hard to define and to measure. Costs are reasonably clear and can be split into two main categories: capital costs of buying or hiring equipment, and running costs for machines and contractors. Further costs are accrued through staff time in preparation (which may be considered as either a capital or running cost) and supervision of the project. Here staff time is kept separate from non-staff costs because funding for pond work varies greatly, depending how or whether staff time is considered.

While all these factors are easy to measure, costs can be presented in two contrasting ways: absolute cost and cost-efficiency. The capital costs and preparation time do not increase dramatically with a larger number or area of ponds, but organisation and supervision time do, so the absolute cost of restoring more ponds is more than counterbalanced by a decrease in the cost per unit area of pond. This is also true when complete restoration is weighed against partial restoration. More ponds and complete restoration are simultaneously more costly and more cost-efficient.

A further factor is cost per unit time. This can be described in terms of absolute costs, or as a measure of cost per unit effort by using cost per unit labour-hour as the unit. The former may be of value where a pond project would take staff away from other duties for an extended period of time, whilst the latter creates an equivalent financial value for the volunteer effort of manual restoration when comparing it to mechanical. Another use of cost per man-hour is to demonstrate match funding in kind to financial backers of the pond project.

The real complications in defining and measuring cost-effectiveness relate to the second part of the formula: effectiveness. Effectiveness is linked not to efficiency but to the results of the restoration work, i.e. which technique offers the best balance between positive and negative effects on the pond flora and fauna. Gains and losses following pond works can be measured objectively (albeit with some provisos or assumptions, as shown in this report), but the most appropriate technique, in terms of its effects on a range of taxa, remains necessarily a subjective decision.

Furthermore, the measure of this effectiveness cannot be reduced simply to cost. For example, there are risks to wildlife associated with pond restoration, and especially with complete clearance; these risks are amplified if multiple ponds are completely restored at the same time – the most cost-efficient option. By contrast, implementing restoration on multiple ponds on a long rotation creates the widest range of succession stages, and as succession is likely to be slowest following complete restoration, this would enable a slower cycle and therefore lower costs.

Finally, it is important to consider grounds other than cost-effectiveness for deciding whether to use volunteer or mechanical labour: for example, where access is poor or the surrounding terrestrial habitat is of value volunteers may be favoured over machines; on the other hand, where there are multiple or large ponds machines may be favoured due to the time, unit labour-hours and inordinate effort required to complete the work manually. Machines may also be favoured on health and safety grounds for restoring deep ponds.

6.2 Case study: Hampton Nature Reserve

There are too many cost factors to list all the variables: capital costs, running costs, staff preparation time, salaries and overheads will all vary between organisations and projects. However, Table 9 illustrates some of the costs associated with complete mechanical and partial manual clearance.

Table 9. **Estimated cost of whole pond restoration using machinery vs. restoration of 15m by volunteers.**

Management	Task	Unit	Duration/amount	Cost per unit	Total cost
Mechanical	Clear the silt from a medium size pond and set it aside	Hours	3	£26	£78
	Dumper time to move spoil away, if necessary	Hours	5	£25	£125
	Transport of machinery	Hours	2	£275	£550
	Staff time to supervise contractors	Hours	10	£25	250
	Total Mechanical				**£1003**
Manual	Purchase equipment	Pieces	10	£25	£250
	Waders and other safety kit	Pieces	5	£35	£175
	Staff to supervise volunteers to clear 15 m	Hours	20	£15	£300
	Total Manual				**£725**

In this case study the capital costs of complete restoration were £550 and the running costs £453, totalling £1,003 for the complete restoration of a single pond. Partial mechanical restoration would have the same capital cost but a somewhat reduced running cost. The capital costs for manual partial restoration were £425 and the running costs £300, totalling £725 for the partial restoration of a single pond. Note that as the capital costs represent acquisitions rather than hire fees, any future management capital costs would be zero.

This data shows that mechanical restoration is about 30% more costly than manual restoration, and complete mechanical restoration the most costly technique of all. Partial manual restoration cost 72% as much as complete mechanical, but restored a much smaller area. If only one pond is being considered, as in this study, complete mechanical restoration is the most cost-efficient per unit area. However, the cost-efficiency of all techniques would increase with the number of ponds - which technique would be most cost-efficient would depend on the time it takes for the volunteer group to clear the areas (this is less predictable than the more constant digger rates).

Manual restoration with volunteers on small ponds is about 30% cheaper than mechanical restoration, but by its nature slubbing is very labour and time intensive. If multiple or large ponds require restoration, especially complete restoration, our experience suggests that excavators should be hired regardless of the financial implications. This may not be financially feasible, but equally it is not feasible for a regular volunteer team to complete such work.

On Hampton Nature Reserve the most effective technique for *Chara canescens* restoration, taking into account impact on other taxa, is complete restoration. However, effectiveness will always be site-specific, weighing different interests against each other. Along with all the other difficulties with establishing cost-effectiveness, this is why we must rely on principles rather than a simple formula.

7. Implications of the project findings

The primary objective of the Second Life for Ponds project was to recolonise bearded stonewort *Chara canescens* on Hampton Nature Reserve by restoring and creating ponds, and through this work to evaluate four different pond management techniques - new pond creation, complete mechanical restoration, partial mechanical restoration and partial manual restoration - against a control of non-intervention.

In parallel the project was designed to monitor and evaluate the changes resulting from each of these management techniques on other important taxa - aquatic plants and stoneworts, aquatic invertebrates, great crested newts and water voles - in order to establish the most appropriate habitat management strategies for the wildlife community on the Reserve as a whole.

7.1 Bearded stonewort Chara canescens

In total 9 ponds were managed for bearded stonewort *Chara canescens* colonisation and 11 new ponds were successfully dug (of which 3 were monitored). 6 of the 12 monitored ponds were colonised, although *C. canescens* only persisted in 4 of these ponds. It is clear that *C. canescens* can be stimulated to germinate from oospores in ponds where it is not currently found, as well as in newly created ponds, through physical restoration of early succession habitats; it is assumed that, while it is possible that these ponds were colonised afresh, these appearances derive from buried dormant spores.

Table 10 shows the breakdown of colonisation according to management regime (and in comparison with the control ponds where no management took place):

Table 10. **Number of ponds with *Chara canescens* colonisation events.**

Habitat management technique	Ponds with *Chara canescens* colonisation events
(Control)	0 of 3
Partial manual restoration	1 of 3 (Pond 29C(M) in cluster 3) - did not persist
Partial mechanical restoration	1 of 3 (Pond R7 in cluster 1) - did not persist
Complete restoration	3 of 3
New pond creation	1 of 3 (in Cluster 1)

This is a successful result, with 55% of managed ponds and 50% of the monitored habitat work conducted leading to colonisation.

Monitoring of these ponds will continue until *Chara canescens* abundance declines or presence is lost; this will indicate with what frequency to maintain the management cycle to optimise *C. canescens* abundance and pond occupancy; monitoring the subsequent succession of the ponds and decline of *C. canescens* necessarily requires a longer timescale.

Initial results indicate that recolonisations following partial pond clearances do not persist for longer than a year, suggesting that if this restoration method is used a frequent management cycle would be required. However, *Chara canescens* has persisted for the full survey period in both newly created and completely restored ponds; these are therefore techniques which do not demand such frequent management for *C. canescens* success.

As Hampton Nature Reserve is very space-limited, and the terrestrial habitat is locally scarce and of relatively increased value, it is encouraging to know that not only is pond restoration a viable option for *Chara canescens* restoration but also, in the case of complete restoration, a better option than new pond creation.

In conclusion, on Hampton Nature Reserve complete pond restoration is the optimum management strategy for *Chara canescens*.

7.2 Aquatic plants and stoneworts

The pre-existing flora survived or recolonised remarkably well following management: only two species (both algae) were lost, neither of which were of conservation concern. Once seasonal variation is accounted for, species richness increased slightly following partial mechanical restoration and more notably following complete restoration and the creation of new ponds; the latter two techniques continued to show a positive trend at the end of the project's survey period, which might be indicative of further increases in future.

Both partial and complete restoration appeared to boost stonewort species richness, although this boost was only truly sustained in completely restored ponds. The relative dominance of stonewort species was also more variable following management, but most apparent in completely restored ponds. All colonisation of new ponds represents a gain in aquatic species richness, but whilst the trend continued to increase with aquatics generally, stonewort persistence was not so high.

Traditional advice regarding pond restoration for plants recommends restricting management to partial clearances in order to balance the potential losses to perennial plants with the benefits to annual aquatic plant communities such as stoneworts. However, where these latter communities are the dominant interest and the majority of aquatic vascular plants are either unaffected by, or even gain from greater intervention, as was the case in this study, then complete restoration should be favoured.

Complete restoration on Hampton Nature Reserve is especially viable due to the high number of ponds present. Although the site is not known to support any vascular aquatics, an inventory should be made as a matter of routine prior to management; any species found which is disadvantaged by complete restoration can be served either by restricting the number of ponds managed in this way or by maintaining a long rotation of management across the site as a whole.

7.3 Aquatic invertebrates

Habitat management led to considerable species loss, including substantial numbers of scarce species: species richness is broadly highest for - in this order - control ponds, partially manually cleared ponds, partially mechanically cleared ponds, completely cleared ponds and finally new ponds. Conservation interest scores follow a similar pattern, although less clear-cut. It might be assumed that values for partially restored ponds are artificially inflated in part by species unsuited to the new habitat straying in from the unmanaged section. The difference between manually and mechanically cleared ponds may be explicable by the less thorough clearance in manually cleared ponds, resulting in a less disturbed habitat. Alongside the losses habitat management has led to species turnover by creating opportunity for early succession and open structure species not found in more established ponds: this includes three which are Nationally Scarce and 20 not recorded from any of the ponds prior to management.

Even though early colonists arrive rapidly after pond management, colonisation is generally slow, with invertebrate succession slowest in completely cleared and new ponds, which suffer less from strays from unmanaged areas, which may compete with pioneer and early succession species. There is currently little evidence to suggest that completely cleared or new ponds support species which do not also colonise partially cleared ponds, and vice versa; in conjunction, this suggests that to maximize benefit to early succession species (albeit at the expense of existing interests) complete clearance would be the optimum management technique.

The benefits of complete clearance must be balanced against the losses of existing interest; in any isolated pond containing the level of invertebrate interest found here prior to management, or any pond in an old wetland or pond complex that might contain poorly mobile species, complete clearance would be unthinkable. Complete restoration is uniquely viable on Hampton Nature Reserve due to the vast reservoir of later succession ponds. New pond creation should provide similar opportunities, but to date they have not performed as well as completely restored ponds. This is probably because the timescale of the project was too short for a site with such slow succession, and because unlike the other ponds, two of the new builds suffered extreme fluctuations in water level or complete drying out, which would be likely to slow colonisation and development of specialist fauna. Once these ponds become established there is no reason to believe that they will not develop a good invertebrate interest equivalent to that of existing ponds of similar size and profile on the site. However, the benefits of new pond creation must be balanced against loss of terrestrial habitats, and given the large number of ponds on Hampton Nature Reserve complete restoration of existing ponds would be favoured over creating further new ponds.

If management is considered for invertebrates alone the default recommendation would remain, as usual, management for steady state conditions if possible. The ponds cleared for this study were probably close to their richest point, and with management of plant growth might have been kept there for a long time. Steady state management of early succession species could involve the partial clearance of ponds which are already at a quite early stage of succession, with a view to maintaining early succession stages indefinitely. These are valuable for many invertebrates whatever their history, but the best are ancient early succession stages, which have been present in one place for sufficient time to accumulate a rich assemblage.

If this is not possible, rotational partial clearance is the next preferred option. Given the high invertebrate value of the ponds selected for complete restoration the length of the rotation would need careful consideration. Many invertebrates benefit from a long rotation slowed as much as possible. However, much of this rotation would be wasted for early succession invertebrates, as well as for stoneworts, especially *Chara canescens*; given the profusion of ponds on Hampton Nature Reserve short rotations should also be included for these species.

7.4 Great crested newts *Triturus cristatus*

The general trend was to a decrease in great crested newt abundance. Against this background partial manual restoration had no noticeable effect, complete restoration gave mixed results but generally did not seem to be deleterious and partial mechanical restoration (the recommended option for great crested newts) was followed by an increase in abundance. Great crested newts were absent in several new ponds and generally only present in others in low numbers, despite the similarity in habitat to the control ponds, which had much higher abundances.

This suggests that habitat management for the benefit of newts should focus on partial mechanical restoration, but that contrary to expectations complete clearance does not seem to have a negative impact.

7.5 Water voles *Arvicola terrestris*

Water voles were present at all ponds prior to management and were only lost following complete restoration, which renders the habitat unsuitable. The only ponds surveyed where water voles were never present were the new ponds; the previous terrestrial habitat was not suitable and neither was the freshly created habitat around the pond edges.

7.6 Summary

The impact of different management techniques on taxa at Hampton Nature Reserve is summarised in Table 11 below.

		Control	Part manual restoration	Part mechanical restoration	Complete restoration	New pond
Chara canescens		A	(+)	(+)	++	+
Stoneworts		P	=	+	++ ↑	+
Aquatic plants		P	=	+	++ ↑	++ ↑
Aquatic invertebrates	Species richness	1	2	3	4	5
	Conservation interest score*	1	2-3	2-3	4	5
Great crested newts		P	=	++ ↑	?	+
Water voles		P	=	=	-	A

*This trend is not as clear-cut as presented in this summary.

Key:

-	decrease relative to control ponds
=	no different to control ponds
+	increase relative to control ponds
++	increase relative to control ponds and most successful management regime
?	mixed results within treatment group
()	did not persist
A	absent
P	present
↑	trend still increasing at end of survey period relative to control ponds
1-5	1=highest, 5 lowest

7.7 Cost effectiveness

Cost-effectiveness is a difficult concept to measure and compare.

- Manual restoration is always cheaper than the equivalent mechanical work but may become less cost-efficient or viable as the volume of work increases, and is always the most time-intensive.

- Partial restoration is always cheaper but less cost-efficient than the equivalent complete restoration.

- Effectiveness is subjective, site based, and measured in various non-comparable taxonomic units which are not equivalent to cost.

- Effectiveness, restoration technique and number of ponds restored are not independent.

There are also factors beyond cost and cost-efficiency, time and time-efficiency and measures of effectiveness which may influence management decisions; these include, but are not limited to: access, terrestrial habitat, and health and safety.

7.8 Pond Restoration on Hampton Nature Reserve: Conclusions

Where pond restoration is primarily targeting Chara canescens complete clearance is best. In this experiment it had the highest success rates (100%) and once present the species persisted throughout the survey period. This management technique also had the greatest effect in rejuvenating the stonewort community and aquatic plants generally. Against expectations great crested newts did not appear to be adversely effected by this treatment. There was a change in the invertebrate fauna, with reduced species richness and total conservation interest, but these species are widely represented on this site. The new community included otherwise under-represented early succession species, including species of conservation concern, so this management approach is judged to be of value to aquatic invertebrates. Smaller sites without such a reserve of suitable habitat for the later-succession species should weigh up these changes with care. The only taxa studied which was unequivocally negatively affected by complete restoration was the water vole, which was absent from completely restored ponds. However, as water voles hold territories on a larger scale than individual ponds they can withstand the loss of individual ponds, so long as the number and density of ponds completely restored in a single area is limited. In effect this means that even complete restoration of a single pond on this larger scale is still only a partial restoration of the available pond habitat. On sites with many ponds such as Hampton Nature Reserve this is a good illustration of the principle of maintaining through management a mosaic of habitat structures, which in this case are levels of pond succession.

8. Dissemination of results

A range of documents support the Second Life for Ponds Project in order to target specific audiences:

- The executive summary is concise and designed for non-specialists. It includes the premise of the project, and summaries of the methods, results, limitations and management implications. Froglife will focus on disseminating this document and expects it to be the most widely downloaded and read.
- The full report is comprehensive and designed as a contribution to evidence-based conservation; it provides detailed information on the methodologies, results and analyses. In view of its length, however, it is less suited to a wide audience.
- The appendixes, which provide much of the supporting data on water quality and invertebrates, are available online as a supplement to the full report.
- It was necessary to abridge substantially the section on invertebrates for inclusion in the main report. An unabridged invertebrate report is available separately from Froglife in order to do justice to the detailed information and analysis which it contains.
- The factsheet is a very brief summary of the project, offering a rapid overview of its premise, results and implications.

All documents will be freely downloadable as PDFs from the Froglife website: www.froglife.org/hnr/secondlifeforponds.htm

We will work with the following bodies In order to disseminate the findings of this study to other conservationists, land managers, scientists and specialists, for example:

- University of East Anglia
- Plantlife
- Buglife
- Local, regional and national BAPs
- Cambridgeshire Conservation Forum and Oxfordshire Nature Conservation Forum
- Amphibian and Reptile Groups of the UK

A report will be uploaded onto www.ConservationEvidence.com for dissemination through the evidence-based conservation community.

Additionally Froglife will promote the project online through its website, blog and facebook, as well as face to face at public events, talks and through contact with other conservationists.

9. Case Study: Stonewort pond creation at the Whittlesey Brick Pits

The Whittlesey Brick pits cover an area of 500 ha and are the result of over 100 years of clay extraction for brickmaking.

The complex covers a range of habitats including a number of ponds, some of which are naturally occurring in areas of non-draining land on the bottom of the pit and others have been purposely created as part of restoration.

Each main planning area within the brick pit complex is named and separate compartments within these areas are numbered. All ponds and ditches are also individually numbered.

2006

One of these areas, known as Star Pit, was last worked in 2000. In 2006, proposals were put forwards to flood the base of the pit to form an irrigation reservoir for the local farmers (to replace one which they were losing in the current mineral extraction area). In assessing the implications of these proposals on the local ecology, a botanical survey of ponds in the base of the pit was undertaken by Sarah Lambert. Bearded Stonewort Chara canescens was found in a number of ponds.

In August 2006, the national stonewort expert, Nick Stewart, was asked to undertake a more detailed survey of these ponds. Out of a total of 22 ponds and ditches on the base of the pit, seven contained bearded stonewort (one of eight species of stonewort recorded, the others being hedgehog stonewort *Chara aculeoata*, rough stonewort *Chara aspera*, opposite stonewort *Chara contraria*, bristly stonewort *Chara hispida*, delicate stonewort *Chara virgata*, common stonewort *Chara vulgaris* and clustered stonewort *Tolypella glomerata*). The population of *C. canescens* ranged from rare in two ponds to locally abundant in one of the ponds (P1) and the population of bearded stonewort was considered to be of some significance. At the same time, Nick Stewart was asked to survey a number of other ponds in the brick pit complex, and bearded stonewort was also found in a pond created as part of the Kings Dyke West restoration in 2004. (A total of six ponds contained C. canescens.)

In January 2006, a series of 11 pools had been constructed in Kings Dyke Nature Reserve, a 50 ha section of the brick pits that is specifically managed for wildlife and allows access to local schools and the general public through a permit system. Seven of these pools (P10 - P16) would specifically encourage the development of stoneworts. Some of the pools were connected by an overflow channel to a large reedbed (P1) which was known to contain at least four species of stonewort (*Chara aspera*, *Chara contraria*, *Chara curta* and *Chara vulgaris*).

2007

An application for a Schedule 8 Licence was made to Natural England in May 2007 to transfer some of the bearded stonewort from the main pond in the base of Star Pit to four of the new ponds in Kings Dyke Nature Reserve. The licence was received in July 2007.

Translocation of the bearded stoneworts took place on 8th August 2007 by Philip Parker, Peter Kirby and Sarah Lambert. The bearded stonewort was collected from Star Pit - Pond P1, in which the source material lay in beds of only that species to avoid contamination with other species which might in the future prove to be a management problem (including fen pondweed Potamogeton coloratus, itself a nationally scarce species). The source material was collected using a garden rake and then placed in buckets for transfer to the donor site. Each bucket contained c 50% vegetative material and clay substrate in order to collect spores that might be present within the clay. It took approximately one hour to collect enough material to fill 12 buckets. These were then transferred to the receptor site via an open trailer.

Inoculation of the four ponds took place in one of two ways. In two of the ponds, larger clumps (that would fit into two cupped hands) were placed around the edge of the pond c 0.5 to 1m out into the water at a spacing of c 2m, In the other two ponds, the clumps were approximately half the size, at a spacing of 1m.

By the end of the summer, all of the clumps that had been placed in the ponds were visible and it was noticeable that there had been some growth of the plant away from the centre clump of vegetation, suggesting that this had probably originated from spores within the clay that was attached to the clumps.

2008

When the ponds were inspected during March 2008, it was worrying that no bearded stonewort was visible although other stonewort species were. However, in discussion with Nick Stewart, it became apparent that bearded stonewort can act as an annual where water depths are relatively shallow.

By May 2008, new shoots of bearded stonewort became visible in all of the ponds into which it had been inoculated. Over the course of the summer it was also noticeable that in one of the ponds there had been a greater rate of establishment, including a number of shoots away from the main clumps. It became apparent that this pond was being used by the local children as a place to keep cool on hot summer days and their feet were presumably spreading the spores.

In September 2008, Nick Stewart re-surveyed the receptor site and found that bearded stonewort was present in all of the ponds into which it had been inoculated, in frequencies ranging from occasional to frequent. It was however also noted that the bearded stonewort was also frequent in two separate ponds into which it had not been originally translocated. (Presumably the children running from one pond to the next proves that disturbance can be a good management technique.) His conclusion was that the translocation exercise had been a great success.

In 2008, prior to the flooding of Star Pit commencing in Winter 2009, a series of four new ponds were created within Star Pit (P22 to P25) but at a level above the proposed flood level. These ponds varied in depth from 0.5m to 1.0m. A licence was obtained to translocate additional bearded stonewort to the new receptor ponds and this took place on 5th December 2009.

Collection techniques were the same as in 2007. However, as it was winter, the surface of the water was frozen and the ice had to be broken before translocation could commence. Bearded stonewort was placed in all four receptor ponds and, utilising the experience gained at the Kings Dyke nature reserve receptor ponds (the positive impact of the children's feet), it was decided to broadcast the mud over the surface of the water in all of the ponds.

2009

The ponds in Star Pit were next inspected in May 2009. At this stage, two of the ponds (P22 and P24) were completely dry but the bottom two were full of water and both contained a considerable amount of visible bearded stonewort.

By this time, flooding of the pit to form the reservoir which had commenced in March 2009 was complete.

2010

During July 2010, following a dry period in early summer, many of the stonewort receptor ponds in Kings Dyke Nature Reserve (P11, P14 and P15) and three of the four ponds in Star Pit (P22, P23 and P24) were found to be dry.

In September 2010, the ponds were re-inspected and whilst the majority had re-filled with water there was still no evidence of stoneworts in any of the ponds which had dried out. It was noted, however, that other aquatic species such as fen pond weed had survived the drying out.

Pond P15 in the nature reserve contains frequent patches of bearded stonewort (amongst other stoneworts). Other ponds which had remained wet appeared to have abundant stoneworts, but were too turbid to inspect properly.

Within Star Pit, the one pond that had stayed wet, stoneworts were abundant, including some bearded stonewort, but all of the other ponds, even though they were now wet, had no stoneworts visible (the same as Kings Dyke Nature Reserve).

Future works

In discussion with Nick Stewart, it seems as though the occasional drying out of the ponds is actually advantageous for stoneworts, as it prevents the build-up of silts on the base of the pond which would otherwise smother them over time.

Despite this, it is proposed to undertake some habitat management on some of the ponds over winter 2010 to ensure that the ponds do not dry out so frequently in the future. In Kings Dyke Nature Reserve, this will involve a slight raising of sluice to the reedbed to retain a slightly greater depth of water, which can then be drawn off in the summer months to feed the ponds when they might otherwise dry out.

Some of the ponds will require management works sooner than others. The ponds within the nature reserve that are closest to the main reedbed lake in Kings Dyke Nature Reserve have frequent to abundant emergents (such as common reed Phragmites australis and sea club rush Bolboschoenus maritimus) and even though there is still a good representation of stoneworts within the ponds, the emergents will require some management (by scraping with the excavator) in the near future.

The two mitigation ponds within Star Pit which dry annually (P22 and P24) will be deepened to ensure they retain water for a longer period and additional ponds will be added.

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