Ponds and the importance of their history: an audit of pond numbers, turnover and the relationship between the origins of ponds and their contemporary plant communities in south east Northumberland, UK.

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Abstract.

An increasing focus of interest in ponds over the last two decades arose largely because of concerns at the loss of ponds in intensively developed landscapes. In the UK pond numbers declined from approximately 800,000 in the nineteenth century to 200,000 by the 1980s. Since then pond numbers have started to increase. The focus on overall pond numbers overlooks the importance of the history and origins of different pond types. This study combines a detailed map based audit of pond numbers in south-east Northumberland, UK, recorded at seven time intervals since the mid nineteenth century with a survey of contemporary plant communities in ponds with known and distinct histories to examine changes to numbers of ponds and communities associated with ponds with different origins. 222 ponds were recorded in the study area in the mid nineteenth century, 257 in 2005/08. However only 23 of the original ponds had survived with substantial losses and gains at all the map survey dates linked to changed land use from agriculture to coal mining then development of nature reserves and golf courses. Contemporary ponds on nature reserves, golf courses and subsidence ponds supported rather different plant communities to each other, with non native invasives in golf and nature reserve sites, whilst individual reserves differed from one another perhaps due to intentional planting. Surviving old farm ponds were usually degraded. The results show that the history of ponds in a region can create an important cultural biodiversity which pond conservation strategies should incorporate.

Introduction.

The need to translate our growing scientific knowledge about ponds and their wildlife into action for pond conservation has been highlighted by Oertli et al. (2009). Both their plea for action and the strength of the scientific knowledge base were founded on two decades of substantial research which have revealed the importance of ponds and their biodiversity, although for much of the preceding century ponds and their ecology had been overlooked, even rather dismissed. To give a British example of the tendency to belittle the study of ponds; *"…it is, moreover, a field particularly suited to the activities of the amateur, whose humble pond-hunting, if carried out systematically and carefully, may well result in valuable contributions to science*"(Clegg, 1952).

We now know that ponds support a disproportionately high richness of species and variety of communities given their small size (Williams et al., 2004). This pattern is well documented throughout Europe (e.g. Davies et al., 2008; Angelibert et al., 2004; Abellan et al., 2006, Della Bella et al., 2008) and there is some evidence that this phenomenon occurs globally, e.g. Australia (Markwell & Fellows, 2008), South Africa (Froneman et al., 2001), Brazil (Guadagnin et al., 2005) and China (Wang et al., 2005). The rich biodiversity found in ponds at a regional or national scale arises because individual ponds typically support surprisingly different communities to one another, even in ponds close together (e.g. Williams et al., 2004).

The burgeoning growth of pond research was prompted in part because of the loss of these familiar habitats throughout many European countries. The numbers of ponds in western European agricultural landscapes have declined over the Twentieth century as land use practises changed, ponds have fallen in disuse and land has been developed for housing and industry, (Boothby, 1999). Whilst there are fewer examples from beyond Europe the evidence supports broadly similar patterns and processes of loss of ponds and allied wetland habitats, e.g. China (Gu et al., 2008), Japan (Primack et al., 2000), Brazil (Guadagnin et al., 2005) and north America (Gibbs, 2000; McCauley & Jenkins, 2005) combined with a lack of appreciation of the value of ponds (e.g. Australia, Markwell & Fellows 2008). Numbers of ponds in Great Britain fell from an estimated peak of 800,000 in the late ninetheenth century to 200,000 by the mid 1980s, with loss rates accelerating post World War 2 (Rackham, 1986. See Oldham and Swan, 1997; Wood et al., 2003 and Williams et al., 2010, for reviews). Pond loss rates estimated primarily from audits of historic maps from the mid nineteenth to late twentieth century range from 6%-90% (summarised Wood et al, 2003) with some evidence that the rate of loss in the UK was accelerating up to the 1980s (Boothby et al., 1994).

However, beginning in the late 1980s, there were examples of increasing numbers, sometimes linked to specific pond types. A survey of lowland ponds in Great Britain estimated that 2000 new ponds were being created per year between 1990 and 1996 (out of a base number of 228,900, Williams et al., 1998) and that the general decline of ponds had halted. Many of these new ponds were being created specifically for wildlife (Williams et al., 2008) but there were additional sources of pond creation, e.g. forestry (Jeffries, 1991). Ponds in gardens, parks and allotments are also numerous but remain a major gap in our knowledge, both the numbers and their ecology (Wood et al., 2003; Gaston et al., 2004). The most recent estimates of pond numbers in the countryside of Great Britain shows an increase from 425,000 in 1998 to 478,000 in 2007 (Williams et al., 2010), including 18,000 lost and 70,600 gained.

So the stock of ponds in a landscape is not a static patchwork. As ponds come and go over time several fundamental questions arise which are important for the ecology and conservation of any patchily distributed habitat and its wildlife.

1. How many ponds are there at any one time? e.g. Froneman et al., (2001) suggested that the high number of ponds was an important factor promoting the richness of waterbirds on farms in South Africa.
2. Losses, gains and longevity of ponds? e.g. Wood & Barker (2000) described the value of ponds originally created to power textile mills in Huddersfield, an industrial town in northern England; the remaining mill ponds provide a valuable habitat in a post-industrial landscape but most of the sites are neglected or have been lost.
3. The type of pond, representing different patch quality for the wildlife? e.g. Jeffries (2005) showed highly species-specific responses to the habitat quality of adjacent ponds associated with local extinctions and colonisations.

The answers to all three questions are contingent on the origin and history of ponds in a region.

This study presents an example of temporal change to the stock of ponds in a lowland landscape of north east England over 150 years to test of the hypothesis that ponds with different origins will support different wildlife, in this case focusing on the plant communities. Pond conservation is not simply a numbers game. Different pond types are likely to vary in value for wildlife. A simple focus on overall pond numbers may obscure problems. For example Williams et al., (2010) have provided salutary evidence that many ponds in the increasing overall total for Great Britain may nonetheless be poor quality, including new ponds dug for conservation which decline in quality quite rapidly after initial success. The aim of the study presented here is to examine the importance of the history and origins of ponds on local scale as a factor to include in the call to action encouraged by Oertli et al., (2009)

The study area of rural south east Northumberland is primarily a mixed arable and livestock farming landscape but has also been impacted by mineral extraction, industrialisation, urbanisation and the development of additional landuses e.g. protected areas and golf courses. Some of these changes will destroy ponds, others will create ponds but these new ponds are likely to be different to those in the earlier landscape and in different places, altering the position and patch quality of the ponds. The data presented here (1) record the changes to both the number and turnover of ponds recorded on small scale Ordnance survey maps from the mid Victorian period, 1860s, to 2008 and (2) explore differences between the floras of four main pond types with different origins (old field ponds, subsidence ponds, golf course ponds and ponds created specifically for nature conservation) to test the hypothesis that ponds with different origins and histories will support different wildlife, with potentially important consequences for the conservation of pond biodiversity.

Method.

The study area; regional context.

Northumberland is the most northerly county of England, with the lowest density human population of any English county and a rich biodiversity including international and nationally important habitats from upland hills to coastal wetlands (Lunn, 2004). It is not particularly rich in ponds compared to regions such as English pond hot-spots like Cheshire or Suffolk. The county does have good examples of upland bog pools, coastal (often temporary) ponds and, in the south east corner of the county, is noted for subsidence ponds which have developed over the last fifty years over coal mining areas (Beige, 2000). Ponds in this south eastern sector support a rich and varied lowland pond flora and fauna (Adams and Robbins, 1988; Jeffries, 1998) although there is evidence that ponds are often lumped together as “subsidence ponds” when this may not be the origin in every case (Jeffries, 1998). Subsidence ponds are an example of new pond formation that can be found in many countries associated with local mineral extraction industries, e.g. German Rhur over coal and Cheshire (UK) over salt (Bell et al., 2000), Poland over coal (Krodkiewska, 2007), China over coal (Zhenqi et al., 1997). Up until the mid nineteenth century land use in south east Northumberland was largely lowland agriculture but extensive deep and open cast coal mining began to exploit the shallow seams and, in the mid twentieth century, urbanisation occurred. This has created a landscape which is still essentially farmland but with small towns and heavy industry. The last deep mine closed in 2005 but land subsidence continues.

An audit of historical changes to the pond stock.

The numbers of ponds shown on Ordnance Survey maps from the mid nineteenth century up to 2008 were counted within a roughly triangular area from Amble in the north (UK Ordnance Survey NU 26 04) to Ponteland in the south-west (NZ 19 70) and Whitley Bay in the south-east (NZ 36 70), an area of 390 km^2, the whole study area lying within the South- east Northumberland Coastal Plain National Character Area, representing a distinct and coherent landscape (Natural England, 2010. See Figure 1 for national and regional context). Ordnance Survey maps have been produced by the UK government since the mid nineteenth century, in a variety of scales and revised editions produced every 20-30 years. The map scale used for this study was the 1:10000 (or in earlier editions 1:10560) maps. Seven editions of the maps were available between 1846 to 2008 (see Table 1 for dates). The maps were viewed via the web resource EDINA Digimap Historic maps, (http://edina.ac.uk/digimap/) which allows up to four maps to be seen side by side allowing detailed comparison of changes between editions. Edition survey dates were also available using this source. The search area was scrutinised at approximately 1km^2 sections at a time, recording the appearance and loss of individual ponds. All ponds and allied features such as settling tanks, small reservoirs, moats and brick pits were recorded.

There are limits to this method. The survey can only be of ponds recorded on the maps, not of all ponds that existed. Small ponds will be missed by the map-makers. Temporary ponds are also likely to be under-recorded.

Some ponds may have been misidentified or overlooked in the audit. The detail on Ordnance Survey maps of 1:10000 and 1:10560 can be high. The older maps were redrawn from 1:2500 scale series which routinely depicted ponds, although later editions, especially after 1890, were less detailed with the minimum size for depiction of many features being ~4x4m (Oliver, 2005). Despite this detail it is likely ponds will have been missed. Within the 20-30 year gaps between map re-surveys individual ponds could have been created and lost. Also smaller subsidence ponds which dry in most summers are also known to be missing. So, the audit in this example is a minimum estimate of pond density and primarily of ponds of at least 4m diameter.

Characterising the flora of ponds with different origins and histories.

Macrophyte data were collected for four distinct types of ponds; old field ponds (i.e. surviving ponds first shown on earliest edition of the Victorian Ordnance Survey maps, N = 6), subsidence ponds (N=12), golf course ponds (N= 14) and ponds created on nature reserves (N=19). Ponds were only included if they had (1) a known origin and (2) a consistent history. Many ponds were excluded because of varied histories (e.g.subsidence sites which have subsequently become part of nature reserves), lack of evidence for origins (most coastal dune ponds) or small numbers (e.g. bomb crater ponds). Pond macrophytes (including macro algae) were surveyed in either 2007, 2008 or 2010. The survey followed the general protocols of the UK National Pond Survey (Pond Action, 1998); all macrophytes within a pond's outer margin defined by the maximum winter water level were recorded and surveys were carried out between June and early September. Macrophyte abundance was recorded using the Domin scale, a 1-10 categorical scale each category representing a range of % cover used for the UK's National Vegetation Classification survey (Rodwell, 1995). *Callitriche* and *Cardamine* were recorded at genus level because of uncertainty with identification in many cases. The creeping grasses *Alopecurus geniculatus* L.and *Agrostis stolonifera* L., which were both widespread and abundant but could not be reliably separated unless in flower, were also combined as one category for analyses. A few ponds had areas of deeper water (>0.75m) which in all cases was sampled by dredging with grappling hooks on the end of a pole

Conductivity and pH were also recorded (five readings, using field probes from around each pond). Area was measured to the winter maximum using Google Earth Pro,.

The primary purpose of the survey was to characterise the vegetation of the ponds with different origins rather than exploring the detail of macrophyte-environment relationships so the plant data for each pond were summarised using detrended canonical correspondence anaylsis, DCCA (CANOCO 4.5, rare species downweighted. Ter Braak and Smilauer, 2002). One subsidence was excluded from the final ordination because it was so different to all other ponds (in a cereal field, the dried out pond basin dominated by *Matricarea discoidea* DC.), and caused serious bunching of the remaining 50 ponds in the initial ordination. Overall group differences between the four pond types were tested using ANOSIM and SIMPER was used to characterise differences in individual plant taxa between pond types. ANOSIM and SIMPER were run on CAP 3.1.

Results.

Historical audit.

The oldest maps (survey dates between 1846-1869) recorded 222 ponds in the study area, the latest maps (2005-2008) showed 257, a 16% increase and giving a current density of recorded ponds of 0.66 km^2. During the period for which maps were available numbers have ranged from a minimum of 157 on 1992 edition maps to the current high of 257 (Table 1). The most striking patterns are the overall losses and gains. Of the 222 ponds at the start only 23 survived and ponds were lost and gained at every intervening period. Table 1 outlines broad changes to land-use and the local economy which are associated with the loss and creation of different pond types. The great majority of the 222 original ponds are small and associated with farm buildings or in the middle of fields with a few labelled as quarries or brick pits. The characteristic subsidence ponds of the region appear from the 1940s onwards and numbers continue to increase following the closure of all deep coal mines. Many of the nature reserve ponds are on old open cast sites and were created following site restoration. The latest peak count includes 37 ponds on a new golf course created on a restored open cast mine.

The macrophyte communities found in ponds with different origins.

Ninety four macrophytes were recorded (including the two combined grasses). Three species were found which were classified as either very localised, rare or very rare in Northumberland (Swan, 1993), each one in a different nature reserve pond; *Bidens tripartita* L., *Ceratophyllum demersum* L., *Nuphar lutea* (L.) Sm., the latter also found in one golf course pond. Four non-native invasive species were found in nature reserve or golf course ponds; *Azolla filiculoides* Lam., *Crassula helmsii* (Kirk) Cockayne, *Elodea canadensis* Michx and *E. nutalli* (Planch.) H. St. John, along with an ornamental cultivar of *Nymphaea alba* L. in seven of the golf course ponds. Table 2 summarises numbers of taxa found in the different pond types along with environmental data.

Figure 2 shows the DCCA plot for the first two axes (variance explained by axis 1 = 10.2%, axis 2 = 7.1%). The subsidence and golf course ponds form two generally distinct groups. Nature reserve ponds are scattered throughout the ordination, although those from individual reserves (e.g. Hauxley or Druridge Pools) tend to be clustered together and the gradient from the Hauxley ponds (high scores axes 1 and 2) to Big Waters and east Cramlington (lower scores axes 1 and 2) represents a shift from ponds on coastal wetlands (within 1km of sea) to inland reserves. The small number of old field ponds are widely scattered through the ordination but concentrated nearest the subsidence ponds.

Results from ANOSIM and SIMPER are shown in Table 3. The global ANOSIM gave R = 0.304, P<0.001, with pair-wise dissimilarities between pond types of between 77.9 and 82.0%. The golf course ponds were significantly different to all other groups (P<0.001 in all cases), but nature reserve ponds were not significantly different from old or subsidence ponds. The golf course ponds were differentiated by the presence of extensive *Myriophyllum spicatum* L. and *Typha latifolia* L.. Subsidence ponds were characterised by shallow water emergents e.g. *Eleocharis palustris* (L.) Roem & Schult, *Sparganium erectum* (L.) and straggling *Agrostis/Alopecurus* grasses but lacked several submerged species e.g. *Potamogeton* and *Elodea* species found in nature reserve and golf course ponds.

Discussion

This study investigated the changing numbers of ponds for a region of south east Northumberland, using ponds shown on Ordnance Survey maps since the mid nineteenth century. At the start of this period the landscape was almost wholly agricultural with mixed grazing and arable, along with some parks associated with large estates. The area then became the focus of extensive deep and open-cast coal mining with associated development of small towns and has more recently undergone land subsidence as the mines closed. Many mining sites have been restored as nature reserves or developed for recreation into country parks and golf courses. The historical map records of ponds in south east Northumberland show a recent overall increase in the local pond stock in line with recent increases shown for nationwide data (Williams et al., 2010), The Northumberland example shows unusually high recent gains (+137 to a previous total of 157 between 1992 and 2008) primarily because of extensive pond creation on a large new golf course. For comparison Williams et al., (2010) estimated lowland England pond gains between1998 and 2007 at 24%.

The evidence for turnover within the regional pond stock is striking, with losses and gains throughout the approximately 150 year period. The ponds recorded on the Ordnance Survey maps are inevitably an incomplete record, in particular under recording the many shallow, temporary subsidence ponds evident in the field, but nonetheless provide some insight into the changing pondscape which can be linked to changes in regional land use. The current pond stock includes a majority of ponds created for reasons other than primarily nature conservation but which have created a significant resource for wildlife and also reflect the economic and social history of the landscape, an example of cultural biodiversity. The creation of pond habitats for some human purpose which subsequently provide significant habitat for wildlife is a widespread phenomeonon, e.g. urban mill ponds in Huddersfield (Wood &Barker, 2000) or the rectangular water supply ponds in Karstic uplands of south-west France (Angelibert et al., 2004). Conservation should not neglect these regionally and nationally important habitats which may provide a distinct form of cultural biodiversity, reflecting the landscape and its history of use. In addition to these older pond types more recent constructed wetlands have also proved valuable for wildlife, e.g. motorway stormwater retention ponds (Scher and Theiry, 2005) and farm wastewater treatment systems (Becerra-Jurado et al., 2009). Our changing patterns of land use continue to create new pond types.

The mean numbers of submerged, emergent and floating leaved plants from the Northumberland ponds are similar to or higher than comparable data for lowland England as a whole (England mean numbers of submerged 0.7, emergent 5.4 and floating 0.9, Williams et al., 2010) and comparable to ranges from ponds from north-west European lowland agricultural landscapes (means from regions of France, Denmark, Germany and UK 7.8-15.3, Davies et al, 2008). Numbers of emergent species are particularly higher, perhaps because many of all three main pond types are simultaneously large in area but shallow in depth, allowing extensive emergent development and supporting the well documented increase in plant richness with pond area (Jeffries, 1991; Gee et al. 1997, Williams et al., 2010).

The analysis of plant communities showed that ponds with different origins supported broadly distinct communities. The subsidence sites supported diverse communities of mostly widespread plants such as *Sparganum erectum*, *Eleocharis palustris*, *Juncus articlatus* L. and *Lemna minor* L., a pattern also found for the invertebrate communities of these ponds (Adams and Robbins, 1988). Some subsidence ponds near the coast show evidence of brackish influence with high conductivities (Table 2) and species such as *Juncus bufonius* L. and *Ranunculus scleratatus* L. which can withstand some saline influence.

The nature reserve ponds also supported diverse plant communities, the different nature reserves tending to have rather different plant communities to one another (Figure 2). Nature reserve ponds were often much smaller than the other three pond types but were likely to benefit from clustering, which increases local β diversity (Williams et al., 2008). Many have been subject to planting. Intentional introductions are known to have taken place at the Hauxley and Big Waters reserves included in this study, often extending the range of regionally rare species (e.g. *Nuphar lutea* in one pond at Hauxley) or species not normally found in Northumberland's lowland ponds (e.g. *Menyanthes trifolia* L., again found in a pond at Hauxley but a plant of upland habitats in the county). Historical planting has included species which are outside of their national range in north-east England (Swan, 1993) , e.g. *Sagittaria sagitifolia* L. and *Hottonia palustris* L. found in a pond at Big Waters nature reserve in 1992 but lost by 1994 and *Butomus umbellatus* L. at Hauxley (1995, lost by 1997). None of this planting was planned or authorised by the site managers but seems to have happened due to good intentions of volunteers. The golf course ponds were also planted on their creation in 2003.

The presence of invasive species only at nature reserve or golf course ponds supports local anecdotal data that management may be an significant source of infestation, a generic threat to pond habitats (Oertli et al., 2009). This was particularly so for *Crassula helmsii* , a problematic invasive in the UK (Dawson & Warman, 1987) which was first recorded in Northumberland at a demonstration wildlife wetland at the Gateshead Garden Festival in 1990 (pers. obs.). The planted up ponds on nature reserves and golf courses are a Trojan horse bringing non-native species out into the countryside. No non-native species were found in the subsidence ponds all of which were chosen specifically because they were not in nature reserves so tend to be unvisited and unmanaged and perhaps as a result have escaped the introduction of non-native species. Similar tensions arising from ad hoc management, primarily fish stocking by anglers, have been described for old industrial mill ponds in the UK; stocked sites had reduced macroinvertebrate diversity but were less vulnerable to draining or loss to development (Wood et al., 2001). Other introductions are straightforwardly a problem, for example invasive crayfish moving out from golf course ponds into surrounding wetlands (Larson & Olden, 2008). Non native invasive pond plants have been associated with more developed landscapes (Lougheed et al., 2008; Matthews et al., 2009) due to environmental stresses such as nutrient enrichment, more colonisation sources nearby and planting up done without consideration for local ecology. In the present study the nature reserve and golf course ponds are in more actively managed and visited sites than the subsidence ponds which were predominantly in amongst inaccessible low intensity grazing farmland.

The potential of golf courses as good wildlife habitat has been recognised globally (e.g. UK, Tanner & Gange, 2005; Australia, Hodgkison et al., 2007; USA Colding et al., 2009), especially in comparison to adjacent intensively farmed or urbanised landscapes. Golf course ponds can make good amphibian habitat, especially for species which avoid urbanised landscapes, as long as the ponds have natural microtopography and native plants (Hodgkison et al., 2007). Colding et al., (2009) found invertebrate richness in golf course ponds was comparable to ponds from nature reserves and parkland, although the golf course ponds tended to be more homogenous, a result echoed in the current study. The Northumberland golf course ponds supported a comparatively rich flora, benefitting from naturalistic morphology and clustering which are generally associated with high pond biodiversity (Williams et al., 2008) and in line with recent work suggesting newer ponds can rapidly gain high numbers of taxa which are lost as ponds age (Williams et al., 2008, 2010).

The small number of old field ponds were a disappointing remnant. Of the six ponds one was completely overgrown with dense *Salix* sp. and lacked any other plants, a second held only filamentous algae, a third supported a diverse flora widespread but also shoals of large goldfish (*Carassius auratus* L.).

Several pond types were not included in the study. Coastal dune ponds were widespread but their origins are usually uncertain. Dune ponds support distinct plant communities so are likely to reinforce the result of this survey that ponds with different origins support varied wildlife. No urban ponds were included, again perhaps a distinct type. Small numbers with unusual origins such as bomb crater and quarry ponds also exist in the area. Given the distinct communities associated with the three main pond types in this study it is likely that the ponds with other origins would also add variety. Differences may have arisen if the origins were responsible for or associated with distinct environmental variation, e.g. some of the subsidence ponds had high conductivities probably due to saline intrusion, but the majority of ponds showed broadly similar ranges of characteristics

(Table 2). No pond type had a monopoly of quality, either in terms of total richness or unusual species. Subsidence, golf and nature conservation ponds all contributed to the regional pondscape, with the subsidence ponds an unusual feature of the region creating a distinct Northumberland biodiversity, a legacy of the coal mining industry. Many landscapes around the world will have similar combinations of natural and artificial pond types creating distinct pondscapes e.g. water balancing ponds in Sweden, (Thiere et al., 2009), golf course ponds in the USA (White and Main, 2005) and farm dams in Australia (Brainwood and Burgin, 2009).

In summary the survey of mapped ponds in south east Northumberland over the last 150 years did not show a simple pattern of pond loss. Instead there have been losses and gains throughout the period with the result that the density of ponds remained broadly similar from the mid nineteenth to late twentieth century. However most individual ponds shown on the oldest maps have been lost whilst new ponds with different origins have appeared. The older ponds were primarily small ponds in fields or adjacent to farm buildings and presumably used as part of the agricultural economy. New ponds have been primarily subsidence ponds or dug out purposefully for nature conservation or as golf course hazards. Ponds from all three of these newer types supported relatively high numbers of locally representative pond plants, although each type tends to support distinct communities adding to the overall regional pond biodiversity.

These results suggest that the conservation of ponds and their wildlife in this region should not rely solely, or even primarily, on ponds within nature reserves, a pattern that is likely to apply in all countries where varied land use and histories creates a distinct cultural biodiversity of pond types, e.g. UK mill ponds (Wood and Barker, 2000), French agricultural ponds (Ruggiero et al., 2008) and Polish subsidence ponds, (Krodkiewska, 2007). Nor is the conservation of pond biodiversity simply about the numbers of ponds in a landscape; one pond cannot be assumed to act as a simple substitute for another in basic tallies of overall numbers. Pond conservation should also have regard to the origins, histories, positioning and uses of ponds to conserve to totality of the cultural biodiversity of these very familiar but significant habitats.

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Table 1. Total number of ponds recorded on 1:10560 and 1:10000 UK Ordnance Survey maps in the south-east Northumberland coastal plain. Map edition dates refer to the survey or revision dates for the individual sheets so are often a range due to variation of revisions within the study area. Land use and major changes show broad developments of land use and management within the area coincident with revised editions of the maps.

	OS Map edition survey dates						
	1846-69	1898-99	1924	1949-51	1977-84	1992	2005-2008
Number of ponds on maps	222	164	170	236	163	157	257
Numbers of original ponds left	222	140	122	98	40	30	23
Pond losses		-84	-18	-25	-161	-65	-37
Pond gains		+26	+24	+91	+88	+59	+137

	Land use & major changes throughout the study period						
	1846-69	1898-99	1924	1949-51	1977-84	1992	2005-2008
Land use and changes	Rural, farming						
		Deep coal mining begins, villages expand, slag heap ponds, loss of farms					
				Subsidence ponds appear on maps		Subsidence ponds increase	
					Extensive open cast mining		
						Nature reserves, many on restored open cast sites	
							Major golf course development

Table 2. Summary characteristics of the four pond types included in the survey. Definitions of submerged, emergent and floating leaved taxa follow the UK National Pond Survey lists (Pond Action, 1998). Terrestrial taxa are an additional category comprising a few species not primarily associated with wetland habitats. Data are given as mean + 1 standard deviation (minimum, maximum). The non-native taxa data list the numbers of ponds in each category from which the named non-native species were recorded.

	Pond type			
	Old Field ponds (N=6)	Subsidence ponds (N=12)	Nature reserve ponds (N=19)	Golf course ponds (N=14)
Submerged taxa	1.3 + 1.5 (0, 3)	0.7 + 0.9 (0, 2)	1.4 + 1.5 (0, 4)	2.6 + 1.3 (1, 5)
Emergent taxa	6.2 + 5.3 (1, 13)	7.9 + 5.0 (1, 19)	8.9 + 3.1 (5, 16)	10.8 + 3.4 (5, 15)
Floating leaved taxa	0.8 + 0.8 (0, 2)	0.7 + 0.7 (0, 2)	1.4 + 1.1 (0, 3)	1.6 + 0.6 (1, 3)
Terrestrial taxa	1.0 + 1.3 (0, 3)	2.0 + 2.2 (0, 8)	0.6 + 0.6 (0, 2)	0.5 + 0.8 (0, 2)
Non native taxa, found in N ponds			*Crassula helmsii*, 4 *Elodea nutalli*, 1 *Azolla filiculoides* 1	*Crassula helmsii* 5 *Elodea nutalli* 4 *Elodea canadensis* 4
pH	7.0 + 0.29 (6.5, 7.2)	7.3 + 0.67 (6.4, 8.3)	7.0 + 0.74 (6.1, 8.9)	7.7 + 0.51 (7.0, 8.7)
Conductivity (µS cm)	745 + 444 (281, 1320)	1718 + 1628 (157, 5854)	664 + 400 (257, 2000)	287 + 53 (187, 377)
Area, m^2	1045 + 856 (175, 2233	1986 + 2224 (168, 8300)	1646 + 2802 (10, 9665)	626 + 404 (88, 1645)

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Table 3. ANOSIM and SIMPER results. The global ANOSIM result gave R= 0.304, P= 0.001. The mean similarity within each of the four groups is given in the first row of the table (Sim.). The table then gives ANOSIM P values for differences between pairs of pond types and the mean dissimilarity of each pair of pond types, (Dis.). The top five taxa contributing to differences between each pair are then listed along with % contribution and which pond type of the pair they characterise (N= nature reserve, O = old field, S = subsidence and G = golf course ponds).

	Nature reserve ponds (Sim.= 23.5%)	Old field ponds (Sim. = 14.7%)	Subsidence ponds (Sim. = 36.4%)	Golf course ponds (Sim. = 39.4%)
Old field ponds	P= 0.080, Dis. = 82.0% *Eleocharis palustris* 5.9% N *Agrostis/Alopecurus* 5.6% O Moss 4.9% N Lemna minor 4.6% N *Glyceria fluitans* 4.4% N			
Subsidence ponds	P= 0.072, Dis. = 75.9% *E. palustris* 7.0% S *Agrostis/Alopecurus* 6.3% S *Sparganium erectum* 5.0% S Moss 4.5% N *Polygonum amphibium* 4.0% S	P= 0.027, Dis. = 76.4% *E. palustris* 9.5% S *Agrostis/Alopecurus* 10.1% S *S. erectum* 6.5% S *G. fluitans* 6.3% O *P. amphibium* 5.0% S		
Golf course ponds	P= 0.001, Dis. = 77.9% *Myriophyllum spicatum* 6.3% G *E. palustris* 4.7% N *Moss* 4.3% N *Typha latifolia* 3.1% G *Juncus articulatus* 2.6% G	P= 0.001, Dis. = 82.0% *M. spicatum* 7.6% G Filamentous algae 4.4% O *Agrostis/Alopecurus* 4.3% O *T. latifolia* 4.3% G *E. palustris* 3.0% G	P= 0.001, Dis. =79.4% *M. spicatum* 6.7% G *Agrostis/Alopecurus* 5.6% S *E. palustris* 4.8% S *S. erectum* 4.3% S *T. latifolia* 4.2% G	

Figure 1. The study area. (a) The map audit of historical ponds and botanical survey of contemporary ponds took place within the south east Northumberland coastal plain in north east England, highlighted in black in the map of Britain. (b) The study area is depicted more precisely by the triangle from Amble in the north, down to Whitley Bay in the south east and Ponteland to the west of Newcastle

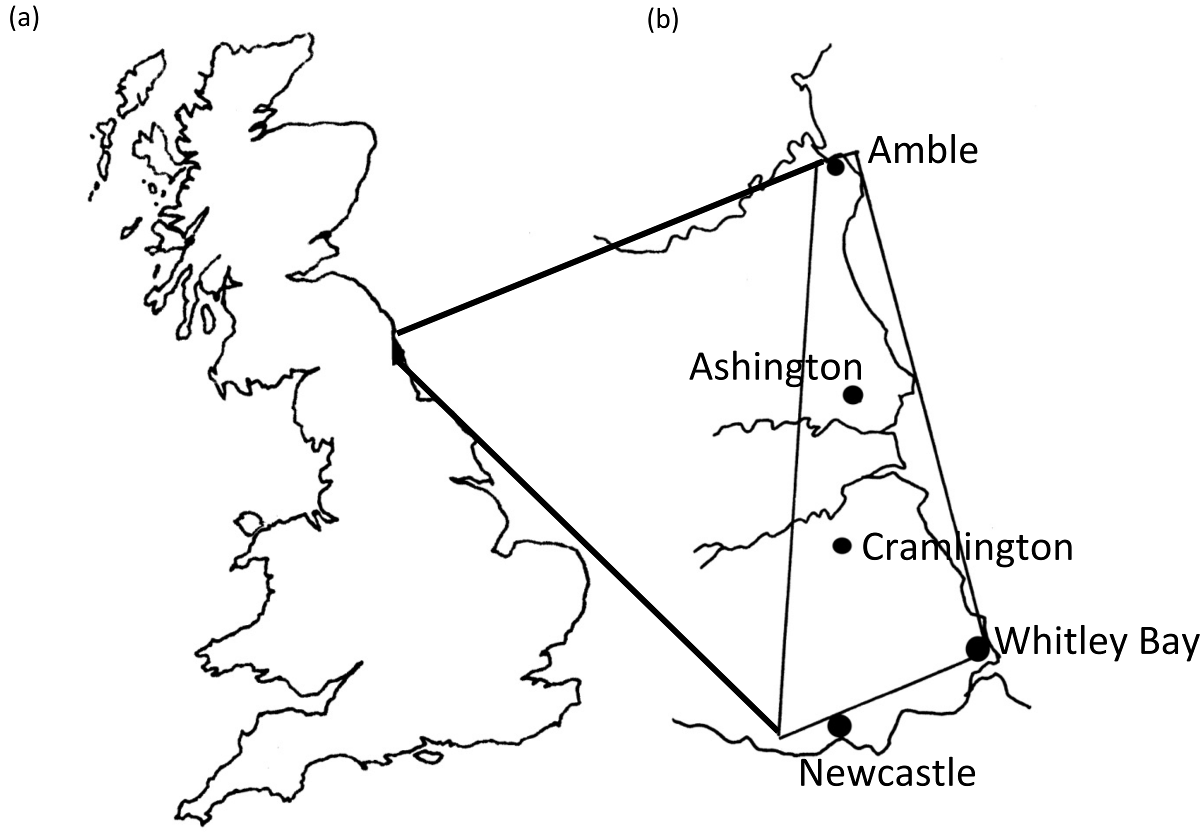

Figure 2. DCCA ordination axes 1 and 2 for 50 ponds using macrophyte data (Note one subsidence pond of the original 51 ponds surveyed was excluded from the DCCA because it was so different to all other ponds causing the other 50 to be very clumped) . Pond types based on their origins are shown as follows; old field ponds +, subsidence ponds ●, golf course ponds ○ whilst the ponds from different nature reserves are additionally distinguished from one another as Hauxley nature reserve ponds▲, Druridge Pools Δ, Ellington Δ, East Cramlington □,and Big waters ■ .