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RANUNCULUS SUBGENUS *BATRACHIUM* IN LOWLAND CHALK STREAMS: A REVIEW

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Covering picture:

Artistic adaptation of photograph of *R. pseudofluitans* by Alexander J.W. Poynter, 2010

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EXECUTIVE SUMMARY

The necessity for improving conservation and management strategies in lowland chalk streams is of great importance in order to meet environmental targets and for the benefit of landowners and management groups. The advancement of scientific research is of vital importance in order to aid the development of such strategies and protocols. Focus in recent years has been on the *Ranunculus* subgenus *Batrachium* group of taxa, as they provide a keystone influence on the chalk stream environment, and the past decade of research has provided a wealth of new knowledge regarding the form, function, ecology and management of this diverse and adaptable group of taxa. An updated review of the scientific literature has been long overdue. The following provides a summary on what is covered in this report:

- Significant scientific advancements in this field have come in the form of ecological understanding, with only a handful of studies being approached from a morphological, physiological, or conservation and management angle.

- Focus appears to be on the detrimental impacts on *Ranunculus* from environmental parameters, with flow (velocity as the primary component), nutrient enrichment, suspended sediment interactions, siltation and herbivory, acting as the main areas of study.

- Cutting has also been highlighted as an area of importance, particularly due to its influence in active river management.

- Key areas of research have been recommended from the findings of the review. As a starting point, the clarification of the taxonomy of the subgenus is much required, as many identification issues still plague survey work.

- The development of our understanding into the distribution and status of *Ranunculus* and the wider macrophyte community is also an issue that has been highlighted. A critique of the existing macrophyte survey techniques should be undertaken also.

- More focused work on flow, sediment dynamics and nutrient dynamics are required, and investment into studies examining the impacts of swan grazing should not be undervalued.

- As a final recommendation, detailed studies into the effects of cutting are necessary, as currently there are issues with confounding effects in multivariate community work in chalk streams, and the applied nature of cutting as a management tool could easily be tailored to accommodate conservation needs.

- The impacts of environmental variables on *Ranunculus* should be considered in a multiple parameter approach, as many studies have previously focused on singular environmental responses, yet have suggested the involvement of other variables with little further progress made to include them. It is clear that this is an increasingly important influence on the dynamics of submerged macrophytes in chalk streams, and future research should be directed towards studies that consider the implications of multiple interacting variables.

1. INTRODUCTION

Ranunculus subgenus *Batrachium* are a group of submerged fine leaved macrophytes (Dawson *et al.*, 1999), considered a key influence on the chalk stream environment for their ability to affect flow dynamics, silt deposition and for their role as essential refugia for macroinvertebrate and fish populations (Hearne and Armitage, 1993; Wright *et al.*, 2002; Gurnell *et al.*, 2006). They have, for many centuries, been an important consideration in the management of the chalk stream ecosystem, and more recently have developed into an important conservation tool for the floral and faunal communities of lowland chalk streams.

Occurring predominantly in areas of chalk geology, the local water resources, economy and ecology are often dominated by the presence of chalk streams, and with submerged macrophytes providing the keystone constituent in such complex systems, it is understandable that research, conservation and management interests on this topic have become increasingly prominent in recent years.

These interests have been enhanced of late due to a perceived decline in water quality and health status of the plant communities. As pressures grow on local resources (through increasing development and agricultural activities, water abstraction, changing management practices and land use, and climate change, amongst others), an overall deterioration in river conditions has been noted as occurring in some systems, with the term ‘chalk stream malaise’ often being coined to represent this. From a management and conservation perspective, therefore, it is essential that our knowledge and understanding of the ecology of keystone macrophytes in these ecosystems is adequate in order to support this. Whilst many studies have taken place over the last three to four decades, to date there are still many aspects of the ecology of *Ranunculus* that are unclear and often inadequately covered to make any informed management or conservation decisions on.

This review aims to draw together the past decade of research, with focus on studies involving the *Ranunculus Batrachium* subgenus, and provide guidance for future research. In order to achieve this broad aim, the following objectives have been created:

- To principally focus on studies that directly consider the ecology, form or function of *Ranunculus* subgenus *Batrachium* taxa that are known to occur in chalk streams.

- To collate studies from a broad spectrum of disciplines.
- To develop an overview of the main advances in research on the *Ranunculus Batrachium* subgenus.
- To determine the most appropriate possible avenues for future research, with particular emphasis on technique improvements for management and conservation.

This report does not intend to review all available literature on the topic, and should be thought of as a supplementary update to previous reviews (e.g. Cranston and Darby, 2002).

1.1. Background

The classic British lowland chalk stream is considered a unique environment that has global significance with regards to its conservation. Geologically, classic chalk streams flow over highly pure fine-grained limestone, although in reality many chalk streams, often classified from non-botanical (e.g. fisheries or geographical) perspectives, are streams of mixed catchments, with vegetation quite different from the archetypal chalk river. Generally, however, chalk streams are able to possess limited quantities of sandstone, alluvium or clay, with no impact on channel vegetation (Haslam, 2006).

Renowned for characteristically stable flow conditions, relative high water quality, and high primary and secondary productivity (Harrison, 2000; Heywood & Walling, 2003; Jarvie *et al.*, 2006; Walling *et al.*, 2006; Glasspool, 2007), lowland chalk streams are predominantly groundwater fed, which can account for up to 90% of annual river discharge (Berrie, 1992; Mainstone *et al.*, 1999; Harrison, 2000; Centre for Ecology and Hydrology, 1999). Thermal, physical and chemical conditions are also commonly stable due to this groundwater influence, presenting near-ideal conditions for growth of aquatic plants and allowing diverse communities of macroinvertebrates to develop (Berrie, 1992; Sear *et al.*, 1999). The flows are usually quick, and with little silt input, stable/firm gravelly substrate, and rarely turbid waters, the general appearance of chalk streams is of unusual clarity (Haslam, 2006).

The geographical locations of British chalk streams follow the line of chalk outcrops that occur in the south and east of England (see Figure 1. and Figure 2.), with the most westerly considered to be the River Frome (including tributaries) in Dorset, and the most northerly of the eastern selection being the River Hull in Yorkshire (Haslam, 2006).

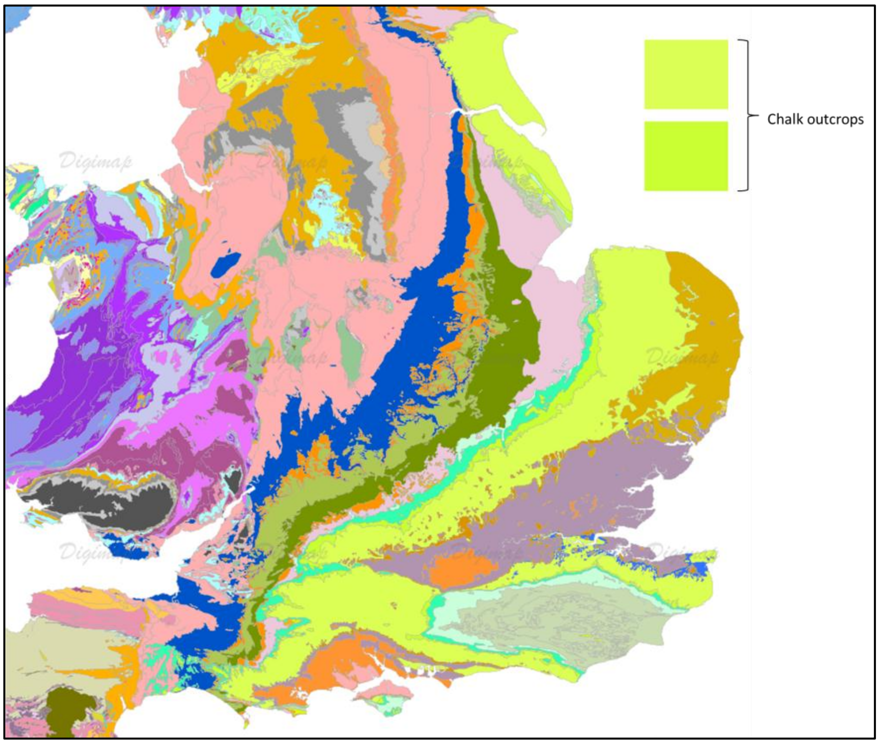

Figure 1. Geological map of England and Wales with chalk outcrop locations highlighted (EDINA, 2011).

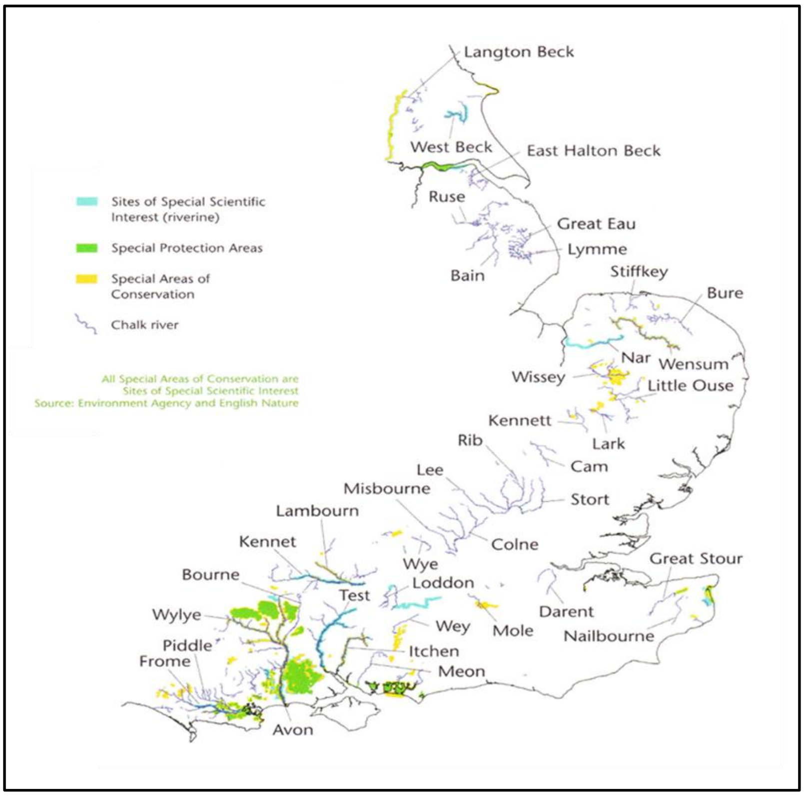

Figure 2. Location map of chalk streams in southern and eastern England (after Glasspool, 2007).

Ranunculus subgenus *Batrachium* (herein referred to as *Ranunculus* spp., or *Ranunculus*), is the dominant keystone macrophyte in chalk streams across England. They are a subgenus well known to have extreme phenotypic and morphologic plasticity, and are often incredibly hard to identify to species level (Rich and Jermy, 1998). Haslam (2006), states that identification of *Ranunculus* spp. can be uncertain in many circumstances, with the distinct possibility of encountering hybrids and intermediates. Furthermore, Haslam comments on leaf length, by suggesting that the same plant species may show differences in form depending on their location in the river, with upstream specimens in shallower waters having shorter leaf form, and downstream, deeper water specimens occurring with longer leaf form.

A principal reason for their success in chalk rivers is that early growth of *Ranunculus* spp. is encouraged by the stable temperature regime aiding above average temperatures during springtime (Haslam, 2006). Coupled with a readily available supply of bicarbonate (HCO_3^-), *Ranunculus*, and most chalk stream macrophytes, are rarely limited by environmental factors (Newman and Raven, 1999).

Chalk stream flora have frequently been categorised according to the vegetation typically present in such habitats, and as such, several classifications have been produced in order to categorise British river habitats. The better known classifications for chalk streams include the NVC classified A17 *Ranunculus penicillatus* ssp. *pseudofluitans* community (Rodwell, 1995), the Type III chalk, limestone and oolite rivers (Holmes *et al*., 1999) and the CB2 vegetation type (Hatton-Ellis and Grieve, 2003). Spink *et al.* (1997), supported the A17 classified community for a majority of chalk streams in a study of *Ranunculus* species distribution. It is worth noting that these classifications hold some importance, as water crowfoots and their respective habitats are protected under the EU Habitats and Species Directive (92/43/EEC).

Issues with the vegetation classifications have, however, been highlighted: Lansdown (2009), states that, whilst these classifications can be applied to communities in chalk streams (with the River Itchen as an example), they are not particularly suited to explaining the vegetation found within the river. This is noted to be due to the low sample numbers used to create the classification, thereby omitting a fair proportion of the overall present taxa, and also by the selection of inappropriate taxa for the classification of the river habitat, by using a majority of marginal plants rather than submergent macrophytes. It is most likely, therefore, that many other lowland chalk streams are inappropriately classified by these methods, and an individual river (or potentially even individual reach) approach to taxa identification should be adopted.

The river habitat classifications contain several commonly associated plant species that are found in conjunction with the typical *Ranunculus* species in chalk streams. These are – the submergents: *Berula erecta* (Huds.) Coville; *Callitriche obtusangula* Le Gall; *Callitriche stagnalis* Scop.; *Lemna minor* agg.; *Oenanthe fluviatilis* (Bab.) Coleman - and the emergents: *Apium nodiflorum* (L.) Lag; *Mentha aquatica* L.; *Myosotis scorpioides* L.; *Rorippa nasturtium-aquaticum* (L.) Hayek; *Sparganium erectum* L.; *Veronica anagallis-aquatica* agg.; and, *Veronica beccabunga* L. (Rich and Jermy, 1998; Hatton-Ellis and Grieve, 2003; Haslam, 2006). Whilst many more species are found growing in such habitats, these are the most frequently observed, and therefore commonly commented upon; further chalk stream plant species will not be mentioned in this report. All of the submerged species are said to be better adapted for tolerating fast, steady flows, rather than spatey conditions, and tolerant of battering and tangling by the water rather than tolerant of scour (Haslam, 2006), which relates well to the generally stable conditions seen in chalk streams.

General plant distribution patterns in the chalk stream ecosystem are seen to correlate with plant dominance changes between upper, middle and lower river reaches, with *Ranunculus* being dominant overall. In the upper reaches, where winterbournes frequent (Holmes, 1999; Westwood *et al.*, 2006), seasonal cycles in community composition occur between submergents during higher flows, and emergents during low/no flow periods. These usually involve *B. erecta*, *Callitriche* spp., and *Ranunculus* during wetted seasons, and *M. aquatica, A. nodiflorum*, and *R. nasturtium-aquaticum* during drier seasons. In the middle reaches, submerged species are dominant throughout, with *R. pseudofluitans*, *B. erecta* and *Callitriche* becoming most abundant, often with *Ranunculus* in the centre of the channel and *Callitriche* at shallow edges in deeper, faster more canalised stretches. *R. nasturtium-aquaticum* and some marginal plants, such as *S. erectum*, are present at the very margins. In the lower river reaches, where deeper waters are more likely, *Callitriche* only occurs in shallower sections, with *Ranunculus* in dominance (Haslam, 2006). Sometimes *R. fluitans* has been observed in deeper, lower reaches of chalk streams, but this does appear to be a rare occurrence (Hatton-Ellis and Grieve, 2003). These are general patterns of plant distribution, so localised variation can be expected, but large shifts in dominance away from this structure may be indicative of altered stream conditions.

Many of the submerged plant species in chalk streams form random patches or 'clumps' on the river bed, making their distribution quite unlike that of bankside or grass-like vegetation which tends to have a more uniform nature (Green, 2005a; Haslam, 2006). Dawson and Robinson (1984), state that this irregularity in spatial distribution has a 'pseudo-braided' effect, where the channels of flow between clumps split and rejoin. Often, plants that are usually unable to grow in open substrate due to environmental constraints, can use larger plants for protection, and plants are sometimes observed clustered together, with multiple plant species frequently comprising a single stand. The patch dynamics concept, developed in stream community ecology by Townsend (1989), likely plays an important part in determining these macrophyte community patterns.

A competitive nature also exists between the three main dominant chalk stream taxa. Ham *et al.* (1981), state that *Ranunculus* spp. are better competitors than both *Callitriche* spp. and *B. erecta* under higher flows, and that reductions in *Ranunculus* biomass, associated with poor discharges, promote a competitive advantage for *Callitriche* and *B. erecta*. Cranston and Darby (1992; 1995; 1997) also concur that expansion of *Callitriche* is associated with the displacement of *Ranunculus*, and is frequently found in co-dominance with *B. erecta*, which also saw expansion at the expense of *Ranunculus*. However, *B. erecta*, unlike *Callitriche*, is also able to grow favourably in faster flowing waters (Haslam, 2006), so its co-distribution with *Callitriche* is likely related to poor competitive nature against *Ranunculus* at higher flows rather than a strict preference to low flows.

1.2. Batrachian *Ranunculus* taxa in chalk streams

The *Ranunculus Batrachium* subgenus is a principally aquatic group comprised of 12 known fertile species, along with multiple hybrids (Rich and Jermy, 1998), although commonly only 6 are known to occur in chalk streams. As the dominant chalk stream species, *Ranunculus* spp. is said to occur at a minimum of 40% of site observations (Haslam, 2006), although abundance is often much higher.

The associated chalk stream *Ranunculus* subgenus *Batrachium* taxa are displayed in Table 1, alongside a brief description of their typical form and general growing preferences.

Table 1. Commonly associated *Ranunculus* subgenus *Batrachium* taxa of lowland chalk streams.

Taxon	Common name	Commonly found	Form description (Rich and Jermy, 1998)	General river preferences (Haslam *et al*., 1975; Haslam, 2006)
Ranunculus aquatilis[$] L.	Common water-crowfoot	Headwaters and winterbournes.	Annual/perennial, spreading-erect when submerged; caespitose when terrestrial. Capillary and laminar leaves. Latter sometimes lacking.	Grows in still to swift flows, up to 0.5-1 m depth, in mesotrophic to eutrophic waters, and on coarse to fine, mineral to organic substrate.
Ranunculus fluitans Lam.	River water-crowfoot	Rare in chalk streams; lower reaches only.	Highly plastic species. Long lived perennial, stems reaching 6m long. Only capillary leaves present, rarely less than 8cm long.	Grows in moderate to swift flows, up to 1 m deep in lowland rivers, in mesotrophic to oligotrophic waters, and on very coarse to medium, mineral substrate.
Ranunculus peltatus[$#] Schrank	Pond water-crowfoot	Headwaters and winterbournes.	Annual/perennial, spreading-erect when submerged, caespitose when terrestrial. Capillary and laminar leaves. Latter sometimes lacking.	Grows in still to swift flowing water, up to 0.5-1 m depth, in mesotrophic to eutrophic waters, and on coarse to fine, mineral to organic substrate.
Ranunculus penicillatus* ssp. *penicillatus (Dumort.) Bab.	Stream water-crowfoot	Rare in chalk streams. Headwaters (with perennial flow), middle and lower reaches.	Long lived perennial, stems reaching 3m long. Capillary and laminar leaves. Latter sometimes lacking. Capillary exceed internode length.	Grows in moderate to swift flows, up to 1m depth, in oligotrophic to mesotrophic waters, and on medium to coarse, mineral substrate.
Ranunculus penicillatus* ssp. *pseudofluitans *[#†] (Syme) S.D. Webster	Chalk stream water-crowfoot	Headwaters (with perennial flow), middle and lower reaches.	As above, but: Capillary leaves only. Leaves often >5 times forked, and can be shorter than, equal, or exceed internode length.	Grows in moderate to swift flows, in shallow, high alkalinity waters, and on medium to coarse, limestone substrate.
Ranunculus trichophyllus[$] Chaix	Thread-leaved water-crowfoot	Headwaters and winterbournes.	Annual or perennial, spreading-erect when submerged, caespitose when terrestrial. Capillary leaves only.	Grows in still to moderate flows, up to 0.5-1 m depth, in mesotrophic to eutrophic waters, and on a wide range of substrate/rock types.

[$] Taxon can occur further downstream, but is constrained to shallower waters; [#] most common chalk stream taxa; * taxon most dominant throughout the length of many chalk streams; [†] species has two common varieties: var. *pseudofluitans*, and var. *vertumnus* (see Table 2 for details).

It is worth noting that, usually, not all of the species listed in Table 1 can be found in any one chalk stream, and most frequently fewer than two species are found in any one river. By far the most common species found in chalk streams is *Ranunculus penicillatus* ssp. *pseudofluitans*, with *Ranunculus peltatus* considered the next most common. In addition, it is also worth pointing out that there are many intermediate forms between the species mentioned in Table 1, but unless any specific mention of these hybrids is made in the literature, these will not be considered in this report.

R. pseudofluitans has two common varieties (var. *pseudofluitans* and var. *vertumnus*), and while both have been recorded in the same river systems, it is said they have different ecological preferences, with var. *pseudofluitans* found predominantly in swift flowing waters, and var. *vertumnus* occurring in slower flowing, or still waters (Rich and Jermy, 1998). It may be that the headwater, and even winterbourne, populations of *R. pseudofluitans*, which have been observed as smaller, more squat looking forms of the plant, are in fact var. *vertumnus*, and the larger, more elongate forms found in the vast majority of the remaining reaches of chalk streams, are var. *pseudofluitans*. Rich and Jermy (1998), state that var. *vertumnus* often takes on a "compact nature" and appears to form "dense, rather neat beds, which are always a very dark green". It is often incredibly difficult to tell these two varieties apart, with only vague, overlapping identification literature having been produced so far. Table 2 highlights the key differences in the forms of these varieties.

Table 2. Key identification differences between var. *pseudofluitans* and var. *vertumnus* (Rich and Jermy, 1998).

	var. *pseudofluitans*	**var. *vertumnus***
Rigidity	Rigid or flaccid	Rigid (semi-rigid/flaccid in winter)
Segment habit	Divergent or sub-parallel	Divergent
Number of segments	30-350	100-900, sometimes higher
Leaf shape when rigid	Obconical	Compact globose
Leaf length	48-385mm	30-70mm
Petioles	12-148mm	5-15mm

Generally, the location of the different *Ranunculus* taxa in the chalk stream environment is determined by distance downstream of the source. *R. aquatilis*, *R peltatus* and *R. trichophyllus* are frequently found in the headwaters and winterbournes of streams, where water depth is shallow enough to enable good growth. These species are sometimes found further downstream, but usually only when water depth is shallow enough. *R. penicillatus* and *R. pseudofluitans* are river wide species, and can grow in any part of the river with sufficient flow, though this tends to be towards the centre of the channel (Haslam, 2006). As mentioned previously, *R. fluitans* can occur in the lower reaches, but only on very rare occasions has this been noted (Hatton-Ellis and Grieve, 2003). Westwood *et al.* (2006), support the comments on species spatial distribution by Haslam (2006), in stating that perennial flowing sections are more likely to support species such as *R. pseudofluitans*, whereas the winterbourne sections will only likely support semi-terrestrial species like *R. peltatus*.

Care must be taken with the identification of *Ranunculus* populations in chalk streams however. Lansdown (2009), notes that, for the River Itchen, Hampshire, the SAC definition states three species of *Ranunculus* are present within the river, while Lansdown's recent study recognised all examined plants as *R. pseudofluitans*. This suggests that, whilst all species presented in Table 1 have the potential for occurring in chalk streams, caution must be taken when assessing the populations of individual rivers, as similar catchments may possess entirely different vegetation assemblages.

2. *RANUNCULUS* SUBGENUS *BATRACHIUM* IN LOWLAND CHALK STREAMS

2.1. The form and function of *Ranunculus* spp.

There are only a handful of studies that can be strictly considered as research on the form (or morphology) and function (or physiology) on the *Ranunculus Batrachium* subgenus. Whilst some studies take into consideration form and function, where they are predominantly from an ecological perspective, as many are, they have been placed in section 2.2.

It is apparent that only very few species have been considered with regards to morphological and physiological studies in the past decade, and by far, *Ranunculus peltatus* has received a majority of the attention. In one of these studies, Garbey *et al.* (2004b), determined that *R. peltatus* had several different growth phases between April and August in the study year, which accounted for elongation, branching, flowering and vegetative dispersal, in that sequence. It is most likely, therefore, that other species in the subgenus would behave in this way, although examination of this would be necessary before any conclusion could be drawn.

In the same study, Garbey *et al.* (2004b), investigated the effects of varying environmental parameters on the morphology of the plants. At three contrasting sites they observed small plants (short internodes and branches) that underwent only small amounts of sexual reproduction (very few flower buds and roots) in nutrient poor sites with little disturbance; plants in nutrient rich sites were longer with a good ability for asexual reproduction (many roots); and shaded, disturbed plants were small in form, but flowered readily and also had good root production. This suggests that *R. peltatus* has a preference for sexual reproduction when disturbed, and favours asexual reproduction under nutrient rich conditions. Garbey *et al.*, support this idea by stating that *R. peltatus* is able to adopt different strategies under alternate conditions, which may contribute towards its successful spread in aquatic environments. Conversely, Mony *et al.* (2007), also studied changes in phosphate (P) concentrations to responses in *R. peltatus* morphology and physiology, and found that there were no responses of branching or root creation to enhanced P concentrations. Interestingly, they did witness the production of buds under low P concentrations. The study was, however, constrained to a 9-day experimental period, which may not be long enough to derive any conclusive results, so comparison between the two studies should be performed with caution.

In a follow up study, Garbey *et al.* (2006), again examined the effects of environmental variables on the morphology and reproduction ability of *R. peltatus*, this time under experimental conditions. It was discovered that a water depth of 32 cm was required for optimum growth, and that, under a variety of velocities, there was no significant difference in the plants fragmentation potential. However, the maximum velocity used was only 0.4 m/s, considerably less than could be expected under storm flow, when fragmentation is most likely. They comment that their fourth parameter, the effects of different substrate types, in their experiment could not be determined, due to the time period used.

The phosphate content of *R. peltatus* was also examined by Garbey *et al.* (2004a), who found that the species stored greater quantities of P than other submerged species in the community, and compared favourably with results from previous studies on *R. fluitans* and *R. penicillatus*. The study also highlighted the inability of *R. peltatus* to accumulate P in eutrophic environments, suggesting that the species could have restricted growth under high nutrient conditions due to other influential environmental variables.

Madsen and Cedergreen (2002), observed that *R. aquatilis* was quite able to satisfy nutrient requirements through just leaf uptake alone. In an experiment in which they removed plant roots growth was unaffected, potentially suggesting that, whilst root uptake has been shown to be the primary source of nutrients, they only really need root mass for anchorage.

In experiments of physical force on *R. pseudofluitans* by velocity, Madsen *et al.* (2001), used tensiometers to show that, during the summer, on larger growth forms (longer, buoyant stems with divergent growth) far more force is exerted on the plants in comparison to autumn flows after the plants have begun to senesce, and plant form has reduced in profile.

2.2. The ecology of *Ranunculus* spp.

In contrast to the preceding section on form and function, there are significantly more studies considering the ecological implications on *Ranunculus* subgenus *Batrachium*. Since this is the case, this section will be split into more manageable sub-sections that concern the principal areas of research for *Ranunculus*; where this applies, it is denoted by the sub-section heading in italics.

Plants can be affected by environmental variables that are both abiotic (physicochemical influences, such as changes in water or channel characteristics), and biotic (biological interactions, such as herbivory by primary consumers and competition with other plants), and are ultimately distributed based on their tolerances to these factors.

Haslam (2006), states that the most important physical variables for affecting plant distribution are, in order of importance: flow; substrate; channel width and depth; drainage order of a channel; and, channel gradient. However, whilst some concurrence is noted, Wilby (1996), considers that the most important variables for influencing macrophytic distribution in southern English chalk streams are: channel gradient; substrate; extent of shading; discharge; suspended sediments; and, turbidity. Wilby notes that water depth, biological oxygen demand, water pH, dissolved oxygen and dissolved nitrogen dioxide are also notable factors acting upon river macrophytes. This does not always present itself so easily, however: German and Sear (2003), studied the River Wylye and unexpectedly found no relationships between abundance of *Ranunculus* and any of the archetypal views for physicochemical river conditions. In reality, therefore, it is likely a combination of these factors that ultimately determines plant growth and distribution.

Complications can arise when attempting to assign causality in chalk stream ecosystems, as basic observations of the macrophyte community are of great spatial and temporal patchiness. Reference should therefore be given to the patch dynamics theory (Townsend, 1989), when considering any form of cause-and-effect study on chalk stream macrophyte communities.

Flow

Flow is understood to be one of the most important factors in determining the success of *Ranunculus* (Cranston and Darby, 2002; Flynn *et al.*, 2002). Wade *et al.* (2002), sees flow as having two different effects on submerged macrophytes: a direct effect (via plant washout), and an indirect effect (through epiphyte removal). Nevertheless, while this might be true, the term ‘flow’ should be considered as three important components: discharge, velocity and depth. Consequently, where necessary, there are sub-sections following this that directly deal with these issues. For studies reporting on ‘flow’ in the ambiguous form, they will be considered here.

As a starting point, it is worth commenting on flow as a mediator in multi-parameter interactions. Under low flow conditions, a manner of other effects are said to occur to the within-river physicochemical conditions (Porteus *et al.*, 2011): generally, velocity is said to decrease, potentially affecting the amount of sediment held in the water (this could be via sedimentation); nutrient concentrations can become enhanced by a limitation to the dilution effect; water temperatures can increase also; and finally, algal proliferation can occur. This was observed by Porteus *et al.* (2011), on a river reach in 1990 usually rife with *Ranunculus,* whereby domination by algae because of two subsequent low flow years caused *Ranunculus* growth to fail. In a review on macrophyte flow controls, Franklin *et al.* (2008), reinforces the well-established idea that the growth of *Ranunculus* spp. in chalk streams is correlated with higher spring/summer discharge, as this is able to wash out epiphytic algal growth. Whilst these views are certainly not the paradigm for all situations involving *Ranunculus* loss, it is becoming an ever more frequent observation on many chalk streams, and with increasing anthropogenic pressures, it may continue to be so (Cotton *et al.*, 2006).

Flow, in one form or another, often appears to show correlations with macrophyte distributions. As an example, House (unpublished), indicates that, in the Wylye and Hampshire Avon, 44% of studied reaches show a relationship between flow and the coverage of *Ranunculus*. Furthering this statement, House goes on to say that April, May and June flows, followed by preceding autumn flows, are the most important flow conditions for *Ranunculus*. Armitage and Cannan (2000), support the view of macrophyte correlations with antecedent flow, although in contrast, they do note that it was with preceding winter flows on the River Frome, as opposed to autumn. Interestingly, Westwood *et al.* (2006), highlight the fact that correlations between flow and macrophyte diversity are frequently lacking from studies, despite flow being one of the overall drivers of ecological diversity. They suggest that this is because of interference from local physical factors. There is, therefore, still uncertainty in comparisons between flow and macrophyte cover, and this is sometimes thought to be due to inadequacies in survey methodology, generated due to the difficult of studying such patchy communities.

Flow resistance (computed using Manning's *n* values), is an important consideration for managing macrophyte stands, as certain species are known to hold water back and raise water levels. Bal *et al.* (2011), supported the idea that *Ranunculus* has high water resistance by producing a high Manning's n of 0.05 $m^{-1/3}s$ for *R. penicillatus*. This resistance, or 'blockage factor', as Green (2006) refers to it, was found to have an non-linear relationship with channel resistance, so increases in blockage factor produced exponential effects on the resistance of the channel. Summarised, Green's study enables a way of quantifying the effects of water resistance to any shape and size of *Ranunculus* stand (or stands) at any particular time, and may therefore help towards the understanding of acceptable plant biomass within the river, and potential thresholds for flooding. Nonetheless, a study by O'Hare *et al.* (2010b), on resistance in rivers near base flow, suggests that the Manning's *n* results could be underestimating blockage in vegetated reaches. Generally, however, O'Hare *et al.*, explain that *Ranunculus* works well in their model for explaining a large proportion of variation in the Manning's *n* value, partially due to the occupation of a habitat niche (preference for gravel/pebble substrate and faster flows, >0.25 m/s). Still, this research may need refinements to take account of variations in flow regimes at various times of the year.

Another way of examining flow resistance on plants is that of drag. O'Hare *et al.* (2007a), examined the drag on *R. pseudofluitans*, known to be one of the most specialist, streamlined macrophytes, and found that it did not differ significantly from the drag of *Callitriche stagnalis* at velocities over 0.3 m/s and *Myriophyllum spicatum* and over 0.4 m/s, both velocities well within the ranges *Ranunculus* is found in. Below these velocities, however, *Ranunculus* had the second lowest drag of the experiment, owing to its streamlined form.

Flow – Velocity

Velocity, considered as one of the three main components of the term 'flow', is often thought of as one of the most important for determining macrophyte growth and abundance, and is particularly well related to *Ranunculus* growth (Chambers *et al.*, 1991; Boeger, 1992; Halcrow Group Ltd, 2004; Gurnell *et al.*, 2006). Reduction and loss of *Ranunculus* was stated as being a major impact of reduced water velocities in chalk rivers, according to Cranston and Darby (2002), who also observed physiological benefits occurring at higher water velocities. However, they do state that, whilst a critical minimum velocity of 0.1 m/s has been previously established for some *Ranunculus* species (Westlake, 1967, 1981; Sweeting, 1986), the ultimate success of the plants is dependent on the consideration of other factors locally, such as depth, siltation and light availability. Halcrow Group Ltd (2004), do infer that further quantifiable evidence is needed before official threshold velocities can be established.

Ranunculus spp. affected flow patterns and sediment deposition in and around the plant stands in a study on the River Frome (Cotton *et al.*, 2006). Flow velocities were recorded at up to 0.8 m/s adjacent to plant stands, dropping to 0.1 m/s within the plant stand, with deposition of fine sediments (predominantly sand) occurring upstream and just downstream of the plant stands. This is supported by the findings of Wharton *et al.* (2006), who recorded velocities of 0.8 m/s outside, with internal measurements of 0.1-0.2 m/s, and Green (2005a,c), who suggests this is due to higher shooting densities. Gurnell *et al.* (2006), note that a severe decrease in water velocity is seen when *Ranunculus* growth increases. These alterations of velocities by plant stands is a point highlighted by Franklin *et al.* (2008), who, after reviewing previous studies, comment that with many of these plant stands in a single reach, a patchy mosaic pattern of plant stands is created, which enhances the growth of *Ranunculus*, further promoting heterogeneous community assemblages; an idea previously mentioned as "pseudo-braided" flows (Dawson and Robinson, 1984), or "quasi-pipe flow" and "quasi-sub-channel flow" (Newall and Hughes, 1995). Conversely, Franklin *et al.*, suggest that, if many stands in a reach combine to create one large stand, water is impounded, velocities are reduced and *Ranunculus* growth is impeded.

An important influence of velocity drops inside plant stands is the increase in sedimentation directly under and slightly downstream of the plant's growing position (Halcrow Group Ltd, 2004; Haslam, 2006; Köhler *et al.*, 2010). This sedimentation has been said to affect both plant distribution and colonisation dynamics, and associated plant stand macroinvertebrates. There are said to be two varying responses to sedimentation, depending on the plant species in question. They can either keep their rooting level during sediment build up, which under slow flows can ultimately smother the plant, or they can vary their rooting level to accommodate for the increased bed height, at the risk of being washed out of the less stable sediments during higher flows (Haslam, 2006). Haslam (2006), states that species which are susceptible to smothering (such as *Ranunculus*) usually grow in locations that see little sediment accumulation, with chalk streams being a prime example. This suggests that chalk streams which see increased sedimentation from reduced flows could potentially increase the risk of macrophyte loss by this method.

Macroinvertebrate colonists are also influenced by the heterogeneity created by the effect velocity has on scour and sedimentation deposition on substrate adjacent to macrophytes, which can subsequently allow colonisation by a richer variety of species (Green, 2005c). Plant species with high shoot density, such as *R. pseudofluitans,* are well known to promote the heterogeneous flow conditions associated with increasing macroinvertebrate richness (Green, 2005c).

The ‘dead-water’ zone in the wake of plants, where turbulence from plant movement interacts with the water column, differs between species which have blunt-ended stands, such as *C. stagnalis* and *Groenlandia densa*, which both saw significantly reduced velocities downstream of the plants (Machata-Wenninger and Janauer, 1991; Green, 2005a). This wake effect may generate zones that are less favoured for the development of other plants, but also provide areas of low flow, where species tolerant of these conditions may colonise (Green, 2005b). Green (2005a), observed that *R. pseudofluitans* had less of an effect on ‘dead-water’ zones, with a considerably smaller wake corresponding with its more streamlined shape. Wharton *et al.* (2006), concurred with Sand-Jensen (1998), where they observed a strong vortex effect in the downstream trailing components of *Ranunculus* stands, first noticed as velocities were higher below the floating vegetation canopy. This may provide some explanation towards why areas of scoured river bed occur behind submerged macrophytes.

Flow – Depth

Although depth is not often considered as flow per se, as the third important factor that has influence on ‘flow’, it shall be classified under this for the purpose of this review.

Whilst water depths are known to be an important consideration (e.g. Newbold and Mountford, 1997), there appears to be little in the way of new direct ecologically relevant research in the past decade. What recent work there is, has reinforced the idea that, with increasing depth, *Ranunculus* biomass reduces (Cranston and Darby, 2002; Wharton *et al.*, 2006), further promoting the theory that *Ranunculus* is happiest in fast flowing, shallower stretches.

Gradient

An often overlooked parameter is that of the river gradient. Haslam (2006), deems gradient to be one of the most important variables, correlating well with flow and macrophyte abundance. On the Wylye and Hampshire Avon (House, unpublished), gradient was seen as the best correlative variable in determining the distribution of *Ranunculus* (although, they note that gradient was included as a substitute for velocity). Furthermore, House suggests that a gradient of 1-3 m/km is likely the *Ranunculus* growth optimum. House also observes the effects of hatches, weirs and leats on gradient, which create low energy, pooling stretches of water upstream, and high energy, swift flowing stretches downstream. *Ranunculus*, consequently, is most abundant approximately 100-400m downstream of these structures, as flow conditions in this range are most favourable to *Ranunculus*.

As a refuge

It is common knowledge that the divergent physical forms of *Ranunculus* spp. are able to harbour great numbers of macroinvertebrates and fish; after all, this is a major reason for the high species richness, abundance and diversity that predominates in chalk streams.

Able to produce a floating canopy in the water column, *Ranunculus* spp. is known to provide a large surface area for the attachment of suspension-feeding invertebrates (Wotton and Malmqvist, 2001). These are said to be comprised predominantly of blackfly larvae (Simuliidae), which feed on small particles and dissolved organic matter in areas of high velocities (Wharton *et al.*, 2006).

An interesting study by Wright *et al.* (2003), investigating floral and faunal (invertebrate) responses to the halted management of a chalk stream over two time periods, showed that there were no significant changes in the mean number of families, mean abundance and mean family richness between the two time periods for *Ranunculus* and *B. erecta,* despite significant in stream reductions in macrophyte coverage. Total macroinvertebrate abundance, however, did decrease significantly on *Ranunculus,* but surprisingly not on *Berula*. It is worth noting, that due to overall reduction in macrophyte area and an increase in gravel and silt between the two sampling periods, the overall site mean family richness and mean abundance of invertebrates did decrease significantly. In another study, on the River Lambourn, Wright *et al.* (2004), observed a greater number of invertebrate families (where *B. erecta* was dominant), than compared to the River Kennet (where *Ranunculus* was dominant). Furthermore, mean abundance of macroinvertebrate taxa was observed to be highest on *Ranunculus* samples on the Frome (Armitage and Cannan, 2000), although taxon richness was lowest on *Ranunculus.* These findings oppose those by Wright *et al.* (2003), although

Armitage and Cannan fail to mention whether there are any management or weed cutting impacts on the site, which may have suggested a reason for these differences.

Nutrient enrichment and epiphytes

Nutrient enrichment, with particular reference to phosphate (P), has been a topic of much debate in chalk streams in recent years. The potential for enhanced nutrient concentrations to influence the distribution and composition of aquatic macrophytes and filamentous/benthic algae is particularly high in naturally stable chalk streams (Carr and Goulder, 1990). However, *R. pseudofluitans* was found to occur at a wide range of phosphate concentrations (0-2.5 mg/g), suggesting that the direct effects of enriched P waters on the growth of the species is minimal (Clarke and Wharton, 2001). This shows that *Ranunculus* spp. must be naturally tolerant to enriched or limited P, so any detrimental effects of enhanced phosphates are likely from an indirect cause.

The growth of epiphytic algae was said to be the basis of *Ranunculus* loss throughout a section of the River Kennet in a study by Jarvie *et al.* (2002a). The blame for the algal proliferation was stated to be from P rich discharges from the local sewage treatment works. Jarvie *et al.* (2002b), also provides support for previous studies that suggests that, while both macrophytes (such as *Ranunculus* spp.) and epiphytes have P removal capacity, it is the uptake by epiphytes that occurs fastest, promoting a competitive advantage. This competitive nature by epiphytes was observed on the River Kennet, after *Ranunculus* declined due to algal expansion (Wade *et al.*, 2002; Jarvie *et al.*, 2004; Palmer-Felgate *et al.*, 2008). Supporting this model, Wilby (1996), found a weak, but existent, correlation between increasing algal concentrations and decreases in *Ranunculus* coverage on the River Test and River Itchen. This was also seen by Wade *et al.* (2002), who produced a model for P-macrophyte-algae dynamics, and showed that epiphytic growth was likely to reduce macrophyte peak biomass by 80%. Surprisingly, they saw that changes in flow were more important than elevation in phosphorus concentrations.

In contrast to the general views on P-algae dynamics, O’Hare *et al.* (2010a), suggests that, as there were no *Ranunculus* plants competitively displaced from their study sites, including those with high P concentrations, *Ranunculus* spp. may be better competitors against epiphytic algae than had previously been thought.

Suspended sediments and sedimentation/siltation

The form of *Ranunculus* spp., as a dense stand of fine divided leaves, is well known for its ability to hold back flows and promote sediment deposition within plant stands (Dawson, 1981), and more recent work has supported this (Clarke, 2002). Gurnell *et al.* (2006), showed that, as *Ranunculus* growth increases, the accumulation of fine sediment particles into variable depth patches increases, although remarkably, it was found that the vegetation of emergent species (e.g. *Sparganium erectum*) was even better able to accumulate sediments, possibly providing further thought as to why sediments generally congregate at the margins in healthy systems. This view is somewhat supported by Heppell *et al.* (2009), who noticed that the sediment deposition and storage was due to growth patterns and form characteristics of particular macrophytes, stating that the more rigid form of *Rorippa nasturtium-aquaticum* has a greater ability to trap sediments than *Ranunculus*. In this respect, watercress, in some places, is most likely a controlling factor regarding the spatial distribution of sediment within the river.

In a two phase experiment of corn pollen release, Warren *et al.* (2009), aimed to investigate the transport of fine particulate organic matter into two distinctly different reaches. At the first site, *Ranunculus* was dominant in the upstream portion, and immediately downstream was a shaded, unvegetated patch. In this site, release into the vegetated section saw 62.5% of the corn pollen trapped, reinforcing the retaining ability of macrophyte stands, and only 41.8% of the corn pollen was trapped in the unvegetated section. In the second site, a different approach was taken; the same site would be used twice, firstly as a release into a vegetated stretch, and secondly, after uprooting all plants, as a release into an artificially freshly unvegetated reach. Most intriguingly, in these releases, the unvegetated reach was more efficient, trapping 58.7% (compared to 51.2%) of the corn pollen, significantly more than in the naturally unvegetated site, all of which is suggested to be related to the act of colmation.

Wharton *et al.* (2006), divulges that the contribution of faecal pellets from blackfly larvae (Simuliidae) is quite significant to sediment deposits at the base of *Ranunculus* stands, providing 60% of the overall fine sediment fraction deposits (25-400 μm). Wharton *et al.*, also comment that up to 2.2×10^8 faecal pellets per m^2 were observed in sediments beneath *Ranunculus* stands, and suggest that the contribution suspension feeders make in transferring organic material to the river bed is very great indeed.

The trapping of sediments and methane (CH_4), has also become a concern with *Ranunculus* stands. A study by Sanders *et al.* (2007), showed that, before substantial *Ranunculus* growth, levels of methane are comparable to those found in groundwater, but after growth has started, and sediments have begun to accumulate, CH_4 concentrations rose close to those in wetland sediments and rice paddy soils. This methane is then released into the atmosphere via transport through the plants. Other studies have highlighted the sediment pore water beneath *Ranunculus* as being sites of high biogeochemical activity. Trimmer *et al.* (2009), determined that there was rapid mineralisation of organic material soon after sediment deposition, and an accumulation of NH_4^+ and CO_2. The CO_2 accumulation was noted to potentially be caused by plant respiration through the roots. Trimmer *et al.*, also agree with Sanders *et al.*, that, due to low velocities in plant stands, most solute exchange is diffusion based rather than through advective flow.

In view of colonisation purposes, Halcrow Group Ltd (2004), highlight that there appears to be a large amount of observational evidence for *Ranunculus* spp. preferences for clean gravel, with negative implications should siltation occur. This is something that has seen little investigation in recent years, but may well be vital for the successful re-colonisation of river stretches lacking in *Ranunculus*.

Reproduction/dispersal

Not regularly studied is the ability for *Ranunculus* spp. to reproduce, either sexually or vegetatively. This is something that needs looking into further, as the successful ability for re-colonisation of river reaches is of great importance, both for the health of the subgenus, and for the status of the macrophyte community as a whole.

The capability of *Ranunculus* to fragment and disperse was examined by Riis and Sand-Jensen (2006). They showed that fragments of *R. peltatus* could travel up to 4.6 km (10% of fragments) downstream from the parent plant, and potentially even as far as 9.2 km (1% of fragments). They comment that this is due to the unidirectional flow in rivers proving beneficial for dispersal opportunities, and also due to the buoyancy of *Ranunculus* stems, holding fragments towards the surface of the water, meaning they were less likely to become snagged on obstacles. Size of fragments was not deemed a significant factor in the dispersal of *R. peltatus*.

Success of fragments to regrow has received some attention. Growth and colonisation potential of *Ranunculus baudotii x pseudofluitans* was surveyed in a study by Riis *et al.* (2009a). They determined that, of all the plants studied, greater than 60% of fragmented pieces of plant were able to regrow, and that larger fragments and fragments with the apical tip present were faster at regenerating, and had greater suitability for colonisation. Even though this hybrid is not likely to be found in any chalk streams, the study gives an indication of the regrowth potential for fragmented pieces of *Ranunculus*. It may well be that regrowth potential is a limiting factor under certain pressures, so the investigation of this could be important for future research.

Herbivory

Some river macrophyte species are evidently highly palatable to mammals and waterfowl alike. It has been well established that several *Ranunculus* species are found desirable by cattle, who frequently consume the submerged vegetation in preference to grass in waters adjacent to fields; and other cases where farmers would constitute large proportions of cattle diet with *R. aquatilis* are not uncommon (Pulteney, 1800; Spink, 1992). The consumption of *R. pseudofluitans* by mute swans also indicated high palatability by waterfowl in studies by O'Hare *et al.* (2007b).

Mute swans (*Cygnus olor*), which feed principally on submerged macrophytes (Rees *et al.*, 1997), are thought to have a significant impact on the growth and success of *Ranunculus*, which may have indirect adverse effects on wild fish and macroinvertebrate populations by removing refugia. It is frequently perceived that the effects of swans should be of top concern, and that the influence of other environmental parameters is only ancillary to this problem. Swan numbers are currently thought to be stable in Britain (Porteus *et al.*, 2011), and had a population total of 31,700 birds, and 6,150 breeding pairs in 2002 (Banks *et al.*, 2006).

It has been duly noted by several authors (Lansdown, 2009; Porteus *et al.*, 2011 O'Hare *et al.*, 2007b), that the grazing of *Ranunculus* by mute swans occurs preferentially over other plant species, to such an extent in some circumstances that there is little left but stumps in the river bed, which may prevent any form of recovery (Wheeldon, 2003; Lansdown, 2009 O'Hare *et al.*, 2007b). It has even been commented that there may be a preferential order of consumption on individual plants themselves, with apical tips being consumed prior to the remainder of the plants (O'Hare *et al.*, 2007b). Observational accounts from landowners on the River Itchen, amongst others, support these remarks, particularly in the absence of a dominant breeding pair, where large groups of juveniles are free to roam up and down a reach at their leisure. Interestingly, past observations have deemed foraging as a random activity, where these observations clearly show selective grazing (Knapton and Petrie, 1999).

In a study on swan grazing and macrophyte biomass in 2004, Porteus *et al.* (2011), found that the number of swans at 46 sites along the River Wylye was significantly correlated with a decrease in *Ranunculus* biomass between May and July, explaining at least 15% of variation. When including the entire study period (April-September), the relationship became non-significant. This is likely due to the confounding inclusion of a pre-expansion phase earlier in the season, where *Ranunculus* has yet to regrow in response to increased springtime flows, and the senescence phase later in the season, where *Ranunculus* declines naturally.

Swan grazing on the River Avon affected 30% of the length of the river in a study by Grieve *et al.* (1999, 2000), and weed-cutting has become more limited in recent years due to poor growth of *Ranunculus* (Porteus *et al.*, 2011). In fact, the impact of swans has reached such a level that even the attention of the national media has been attracted to it, as Porteus *et al.* (2011), noticed from back in 2004 (Elliott, 2004; Fort, 2004).

Porteus *et al.* (2011), note that in years of low flow, the implications of swan grazing are furthered, as lower water levels in the river allow swans access to wider areas of *Ranunculus*. This may well be possible, as Lansdown (2009), indicated that swan grazing during 2005-2006 on the River Itchen showed a substantial decline in *R. pseudofluitans* coverage throughout the river. Cox (2008), suggests that the autumn/winter grazing by swans on the Rivers Test and Itchen has resulted in the total loss of *Ranunculus*, a sentiment echoed by many local landowners.

Herbivory also has detrimental impacts on faunal distributions in chalk streams. Grazing was shown to reduce macroinvertebrate richness by Harrison and Harris (2002), who identified that ungrazed sites had a greater overall taxon richness both amongst the *Ranunculus*, and also on stretches of exposed gravel beds. However, they did also make note that total abundance did not vary between grazed and ungrazed sites, and that bankside vegetation is most important for richness and abundance of invertebrate species.

It is surprising how large an influence waterfowl grazing can have on plant biomass removal also. O'Hare *et al.* (2007b), studied the impacts of mute swan grazing on the keystone chalk stream macrophyte *R. pseudofluitans* on a uniform, unmodified stretch of the River Frome in Dorset. Observations showed that swans spent approximately 61.6% of their time feeding and estimated that ~ 23% of their time could potentially be used in removing *R. pseudofluitans* biomass. This was supported by the observations that *R. pseudofluitans* biomass was 49% lower in grazed sites.

Lansdown (2009), does submit that it is unclear whether *Ranunculus* could be eliminated by swans entirely, under drought conditions, but states that it is a resilient genus, with ability to recover from most pressures upon returning to optimal growing conditions. On observation, this appears to be likely; during the initial spring regrowth phase in 2011, the River Itchen saw low flow conditions, with minimal *Ranunculus* regrowth from the previous year, and many accounts of swan grazing on any stubs attempting to regrow; by the summer, *Ranunculus* had recovered on many reaches. Some reaches still saw little growth by the summer, however, showing that certain issues affecting regrowth still occur throughout the river.

Other ecological considerations

Another problem, often present when concerning the ecology of the *Batrachium* subgenus, is with the physical identification of the species present within a river reach. Lansdown (2007), performed a study to identify the populations of *Ranunculus* on the River Itchen, Hampshire, and found that all of the sampled plants were *R. pseudofluitans*. However, the population actually contained 16 genetically different clones, each showing different behavioural and response characteristics to a variety of environmental and anthropogenic conditions. It is this reason, Lansdown states, that the SAC designation wrongly included *R. fluitans* and *R. peltatus*, as samplers misidentified the various clonal forms of *R. pseudofluitans* as the two other species. Furthermore, inferences of changes in species-level populations were considered impossible, as ecological isolation has not yet occurred, and with hybridisation common, identification will continue to provide sampling errors, until further clarification of the taxonomy has been undertaken. As stated by Lansdown (2009), this taxonomic work is much needed for the future understanding of their ecology.

2.3. Management and conservation concerning *Ranunculus* spp.

Much like section 2.1., there is comparatively little direct research involving *Ranunculus* and management/conservation when compared to those that take an ecological stance. In fact, in certain cases, argument may be given that aspects of the ecological research can be applied into this section, just as certain elements here may have ecological concern also.

Recent focus, particularly within the Environment Agency, has been around the evaluation of currently adopted survey methods for UK macrophytes. As an example, the Mean Trophic Rank[1] methodology was criticised by Lansdown (2009), whom, after an assessment of the suitability of the method in the River Itchen, determined that it had no use as a monitoring method for the condition of the macrophyte community due to its: a) poor ability to imply changes in trophic status, and; b) incapacity for comparison against current vegetation classification methods, in particular the Hatton-Ellis and Grieve (2003), "*Ranunculion fluitantis* and *Callitricho-Batrachion* 'CB2'" classification (although this was noted as being principally a fault of the classification method not denoting the difference between a healthy and degraded system). A thorough assessment of the usefulness of this method is long overdue, along with an in depth evaluation of the method used for LEAFPACS[2] (Willby *et al.*, 2009).

Management considerations in scientific work have been predominantly focused on the effects of weed cutting over the last decade, although even research on this has been limited. *Ranunculus* spp. is often observed by river managers to be the 'preferred species' of aquatic macrophyte to have throughout chalk streams (Cox, 2008). However, in order to promote biodiversity within chalk streams, it has been shown that a well-mixed heterogeneity of plant species is conducive to producing richness of biota (Franklin *et al.*, 2008). Supporting this, Hatton-Ellis and Grieve (2003), state that monocultures of *Ranunculus* are not favourable for the habitat. Cox does note that, whilst there is a preference in species, most river managers felt it important to sustain diversity.

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[1] The Mean Trophic Rank (MTR) methodology is an ecological assessment technique, where observed conditions are compared to reference conditions typical of the surveyed river type (Dodkins *et al*., 2005). It was developed in order to evaluate the impacts of eutrophication at sites in lotic water courses to aid the UK implementation of the Urban Wastewater Directive (European Union, 1991; Holmes, 2010).

[2] LEAFPACS – The shortened name for the Environment Agency's ecological classification scheme for aquatic macrophytes in UK rivers.

Questions on the flowering of *Ranunculus* produced varied responses in a survey by Cox (2008), who spoke to river managers in the Test and Itchen about cutting. Whilst he notes that guidance from Natural England states 25% of plants should be allowed to flower (per 100m stretch of river), some river managers suggested it weakened the plants, and cutting prevents *Ranunculus* from flowering at all on their stretch. Others, in contrast, make the decision to leave the plants to flower as much as possible. Cox does comment that there is a lack of supporting evidence that *Ranunculus* is able to produce a viable seed when cut, so whether the 'pruning' of flowers impacts on plant reproduction capability is largely unknown.

Although the study by Baattrup-Pedersen and Riis (2004), was performed on a Danish stream, not over chalk geology, it is worth highlighting their findings about the tolerance of *Ranunculus* to cutting. They suggest that *Ranunculus* may respond and regrow more quickly to cutting than other river macrophytes. However, it is worth noting that the other macrophytes in question are not usually found on chalk rivers, so this may not accurately reflect the responses seen in British chalk streams. Nevertheless, they also note that, in systems where cutting was not performed, abundance of submerged macrophytes was higher overall, and community diversity was greater. Pedersen *et al.* (2006), observe that *Ranunculus* abundance is strongly positively related to intensively cut streams, but that *Callitriche* spp. and *B. erecta* were negatively associated. This suggests that the effect of cutting, or disturbing, may promote the growth of *Ranunculus*, as seen in the study by Baattrup-Pedersen and Riis (2004).

Cox (2008), gathers that some river managers showed concern that loss of *Ranunculus* through wash-out during the winter was contributing to lower water levels and potential increased bankside erosion if a pre-winter cut was not performed. Although river managers are experienced in understanding the responses of *Ranunculus* to cutting, it may well be worth investing in a future study on timing of cuts, to fully understand how *Ranunculus* regrowth is affected.

Even less studies appear to have been conducted on the impacts of restoration and conservation techniques regarding *Ranunculus*. On restored channelised lowland streams, Pedersen *et al.* (2006), comment that management should be left to a minimum to encourage macrophyte recovery. This may well be an ecologically beneficial and low cost outcome to the restored reach in question, but this self-colonisation will take longer to occur. The transplanting of *Ranunculus* into restored streams in Denmark was shown to be successful, with a high survival rate after the second growing season, and stands that had grown to large sizes (Riis *et al.*, 2009b). Both self-colonising and transplant based restoration methods have to be used with precaution however. Westwood *et al.* (2006), highlight caution for trying to use habitat restoration for promoting growth of *Ranunculus*. They propose that stream flow, whilst important to *Ranunculus* and as an ecological diversity driver, is affected to a large extent by local physical factors. Therefore if restoration work, such as channel narrowing is undertaken, it is suggested that it should be done sensitively in order to promote diversity.

As a single species however, Lansdown (2009) proposes that, while *Ranunculus* spp. are likely one of the most tolerant of submergent macrophytes, for conservation priority, the remainder of the community may require precedence. It could be argued however, that as a vital component of the chalk stream ecosystem, certain species within the subgenus should be considered representative of the overall community, and therefore research priority should focus on them irrespective of tolerance.

3. RECOMMENDED AVENUES OF FURTHER RESEARCH

It is clear from reviewing the literature over the last decade, and from considering the work undertaken prior to this, that there are still large gaps in our knowledge of the *Ranunculus Batrachium* subgenus. In determining what areas of research require further work, the following can be thought of as recommendations (in no particular order), for the future benefit of our understanding, management and conservation of *Ranunculus* in chalk streams:

- **Status and distribution** – Although Spink *et al.* (1997), performed a fairly comprehensive study on the distribution of aquatic *Ranunculus* species throughout the UK, clarification is still required with regards to the range of the subgenus, with particular focus on environmental tolerances. This is especially important when concerning their status (both as populations and communities), as current techniques used for determining macrophyte health appear to be somewhat lacking.
- **In-depth critique of macrophyte survey methods** – Currently, the MTR method (Holmes, 1999), LEAFPACS (Willby *et al.*, 2009) and the MFR (Macrophyte Flow Ranking; Environment Agency, 2002) method are in use today in the UK as macrophyte survey methods for attempting to determine health status of lotic macrophyte communities. While MFR is a conceptual method, in development internally by the Environment Agency, the MTR method has already undergone criticism by Lansdown (2009), who highlights its inability to determine the status of the macrophyte communities in chalk streams, due to their characteristic patchiness. As there do not appear to be any accessible recent accounts of the use of the method in LEAFPACS, it is clear that an in depth examination and critique of these methods is required to determine their usefulness in assessing the health of chalk stream macrophyte communities. This is an important issue, as these methods underpin decision making for conservation targets, and if found to wrongly assess status, could lead to poorly informed decisions for management and conservation. These status assessment methods, however, go hand in hand with our understanding of the taxa, so scientific research needs to be adequate in order to develop robust status evaluation techniques.
- **Impacts of climate change** – Flow regimes of rivers have the prospect of further pressure from the impact of future climate change. Although there have been passing mentions

throughout the review process, it has been difficult to pin down any specific studies that consider the effects of climate change directly. As such an important impending issue, these pressures must be considered in further research sooner rather than later, and applied in two possible ways: firstly, baseline changes in river physicochemical conditions need to be quantified through modelling and hard observation of changing conditions temporally; and, secondly, climate change scenarios should be considered alongside ecological, conservation and management studies.

- **Taxonomic clarification** – As Lansdown (2007; 2009), has suggested, a significant amount of work is still required in clarifying the taxonomy of the *Ranunculus Batrachium* subgenus. With statements about the difficulty (and near impossibility in some cases) of identifying between species within the subgenus (e.g. Rich and Jermy, 1998), it is no wonder that there are many accounts of false recordings and misidentifications in survey work. In fact, this clarification may be vital before any further distribution and range work is undertaken.
- **Swan grazing studies** – Although there has been much interest on the impacts of swan grazing on *Ranunculus* of late, there is still scope for further research in this area. In particular, it is noticeable that studies to quantify these implications at a catchment scale are required. Longer term studies focusing on how swan grazing impacts upon the structure of the plant, and macroinvertebrate, communities would also prove highly beneficial. If both of these points could be fulfilled, it may help lead towards an answer of how much variation in the plant community could be attributed to this environmental concern, which in turn would allow greater precision in determining the variation explained by other environmental parameters.
- **Flow dynamics** – A particular 'hot' topic; the response of *Ranunculus*, as well as the remainder of the plant community, to changes in flow conditions requires a certain amount of advancement. It seems as though a large amount of work pinpoints flow, in one form or another, as one of, if not the most important controlling factor that controls macrophyte distribution. However, what is lacking from the literature is an identification of whether it is flow directly that determines distribution, or whether it is the synergistic nature of flow with other physicochemical riverine parameters. While both of these may be true, further investigative work will be needed to better determine the influence of flow on *Ranunculus* and other macrophytes in chalk streams.

- **Suspended sediment dynamics** – The role that suspended sediments and siltation plays in the chalk stream environment is an important one. With land use change, more sediment may enter the river system through runoff, causing a multitude of unwanted effects to the flora and fauna living there. It has the potential of disrupting the natural dynamics, but there has been little research attempting to quantify these impacts. The ability for *Ranunculus* to trap suspended sediments seems well documented, but the effects of smothering by silt requires further attention. Also, the role sediments play in the nutrient dynamics in chalk rivers seems lacking in the literature.
- **Nutrient/silt/*Ranunculus*/algae dynamics** – The implications of enhanced nutrient concentrations are reasonably well conceived, but investigative work into the dynamics of nutrients with silt, *Ranunculus* growth, and algal proliferation is needed. Some of these elements have been addressed individually, and a conceptual idea of the dynamics is well established, but scientific evidence is very much needed. On this point, however, and as has been suggested previously, it may be that flow is the controlling element in this relationship (Wade *et al.*, 2002).
- **Competitive nature of *Ranunculus, Berula* and *Callitriche*** – Although this has been observed in many studies in the past, the competition of the three main submergent chalk stream species does need to be examined in greater detail. Whilst this may not be a research priority, any work performed in this area can only benefit the understanding of the community dynamic in chalk streams.
- ***Ranunculus* as refugia** – Perhaps principally important as a reinforcement of the significance of *Ranunculus* as a refuge for fish and macroinvertebrates, only a handful of studies have examined the capability of species within the subgenus for providing safety. Therefore, whilst future research into this is not essential for the conservation of the plants themselves, it may help in the provision of supporting evidence to encourage their protection.
- **Response of *Ranunculus* to cutting** – Cutting is a highly significant area of research, particularly as it directly involves the existing management of the river. Some studies suggest that changes such as the number of cuts performed in a season, or even the severity of the cuts performed, can have varied effects on the growth of *Ranunculus*. As such an applied area of research, with great practical benefit, it is somewhat surprising that these questions have not yet been addressed. Also, considering the potentially confounding influence that cutting has on the outcome of field survey work, understanding the impacts

would certainly help towards quantifying and ruling out this component from multivariate analyses.

- **Regrowth, colonisation and fragmentation potential** – Another often understudied element is the reproductive and colonisation potential of *Ranunculus* spp.. The natural ability for reproduction and colonisation is one area that needs further work, but the disruptive possibility from changing environmental conditions could be of great importance to the survival of the subgenus also. This will be an area of research closely related to many of the others mentioned here. As an example, one important aspect that will require investigation is the involvement of siltation with the rooting and colonisation success of *Ranunculus*, both via vegetative and seed production.
- **Multiple environmental parameters** – As more of a general point for the direction of research in chalk stream ecology, it is evident that the plant community within chalk rivers is affected by multiple potential stressors, and therefore future studies should aim to reflect this. After all, multiple interacting variables can have marked differences on biota, compared to those acting singularly.

As a final note, it is understandable that not all of the aforementioned areas of further research will be possible at this time or in the near future, but it would be hoped that these questions will be addressed at some stage.

4. CONCLUSION

The past decade of research into *Ranunculus* subgenus *Batrachium* in chalk streams has provided us with a wealth of new knowledge regarding the form, function, ecology and management of this diverse and adaptable group of taxa.

A good majority of these advancements has come in the form of ecological understanding, with principal focus on the detrimental impact of environmental parameters. The main study areas, which comprised the bulk of this research, involved flow (with velocity as the primary component), nutrient enrichment, suspended sediment interactions, siltation, and herbivory. The importance of cutting has also been highlighted, with several studies showing how crucial the correct management can be to the success of the subgenus.

Consequently, for the future conservation of *Ranunculus*, several key areas of research were recommended. One of the more important starting points appears to be the clarification of the taxonomy of the subgenus, as this fundamental aspect often causes difficulty in the basic identification between species. Developing understanding on status and distribution, as well as a comprehensive critique of the existing macrophyte survey techniques is also recommended. Flow, sediment dynamics and nutrient dynamics were also emphasised as areas of further ecological research, and swan grazing studies were suggested, as the prospective implications here cannot be ignored. Finally, studies looking into the effects of cutting are needed, as this aspect of stream management is currently difficult to quantify and raises issues by potentially confounding the effects of other physicochemical parameters when investigative survey work is being performed.

Whilst flow appears to be one of the most important environmental controls, it is obvious from the literature that there is a developing consensus that the interaction of multiple parameters is predominant in controlling the distribution of aquatic *Ranunculus* species. Indeed, as evidence from many studies suggest this is the primary reason for decline, it would be unwise to focus future research solely on singular environmental parameters.

REFERENCES

Armitage, P.D., Cannan, C.E. (2000). Annual changes in summer patterns of mesohabitat distribution and associated macroinvertebrate assemblages. *Hydrological Processes* **14**, 3161-3179.

Bal, K., Struyf, E., Vereecken, H., Viaene, P., De Doncker, L., de Deckere, E., Mostaert, F., Meire, P. (2011). How do macrophyte distribution patterns affect hydraulic resistances? *Ecological Engineering* **37**, 529-533.

Banks, A.N., Collier, M.P., Austin, G.E., Hearn, R.D., Musgrove, A.J. (2006). *Waterbirds in the UK 2004/05: the Wetland Bird Survey*. BTO/WWT/RSPB/JNCC. Thetford.

Baattrup-Pedersen, A., Riis, T. (2004). Impacts of different weed cutting practices on macrophyte species diversity and composition in a Danish stream. *River Research and Applications* **20**, 103-114.

Berrie, A.D. (1992). The chalk-stream environment. *Hydrobiologia* **248**, 3-9.

Boeger, R.T. (1992). The influence of substratum and water velocity on growth of *Ranunculus aquatilis* L. (Ranunculaceae). *Aquatic Botany* **42**, 351-359.

Carr, O.J., Goulder, R. (1990). Fish-farm Effluents in Rivers – II. Effects on Inorganic Nutrients, Algae and the Macrophyte *Ranunculus penicillatus*. *Water Research* **24**, 639-647.

Centre for Ecology and Hydrology (1999). *The Flood Estimation Handbook*. Centre for Ecology and Hydrology, Wallingford, UK.

Chambers, P.A., Prepas, E.E., Hamilton, H.R., Bothwell, M.L. (1991). Current velocity and its effect on aquatic macrophytes in flowing waters. *Ecological Applications* **1**, 249-257.

Clarke, S.J., Wharton, G. (2001). Sediment nutrient characteristics and aquatic macrophytes in lowland English rivers. *Science of the Total Environment* **266**, 103-112.

Clarke, S.J. (2002). Vegetation growth in rivers: influences upon sediment and nutrient dynamics. *Progress in Physical Geography* **26**, 159-172.

Cotton, J.A., Wharton, G., Bass, J.A.B., Heppell, C.M., Wotton, R.S. (2006). The effects of seasonal changes to in-stream vegetation cover on patterns of flow and accumulation of sediment. *Geomorphology* **77**, 320-334.

Cox, J. (2008). *Rivers Test and Itchen Weed Management Review*. Jonathan Cox Associates Ltd, Ecological Consultancy, Lymington.

Cranston, L.E., Darby, E.J. (1992). *Rivers Test and Itchen Macrophyte Survey: 1991 – 1992.* Freshwater Environments Group, Loughborough University, Loughborough, UK.

Cranston, L.E., Darby, E.J. (1995). *Rivers Test and Itchen Macrophyte Survey: 1994.* International Centre of Landscape Ecology, Loughborough University, Loughborough, UK.

Cranston, L.E., Darby, E.J. (1997). *Rivers Test and Itchen Macrophyte Survey: 1996.* Loughborough Ecologists, Loughborough, UK.

Cranston, L.E., Darby, E.J. (2002). *Ranunculus in Chalk Rivers: Phase 2*. Environment Agency R & D Technical Report W1-042/TR. Environment Agency, Bristol.

Dawson, F.H., Robinson, W.N. (1984). Submerged macrophytes and the hydraulic roughness of a lowland chalk stream. *Verh. Internat. Verein. Limnol.* **22**, 1944-1948.

Dodkins, I., Rippey, B., Hale, P. (2005). An application of canonical correspondence analysis for developing ecological quality assessment metrics for river macrophytes. *Freshwater Biology* **50**, 891-904.

EDINA (2011). Geology Digimap (online). Available at http://digimap.edina.ac.uk. Accessed on 29th June 2011.

Elliott, V. (2004). Anglers in a flap as swans wreak havoc on rivers. *The Times*, 23rd August.

Environment Agency (2002). *Resource Assessment and Management Framework. Report and User Manual (Version 3).* R&D Technical Manual W6-066M. Environment Agency, Bristol.

European Union (1991). Directive 91/271/EEC 21 May 1991. Urban Wastewater Directive.

Fort, T. (2004). The case for killing swans. *The Spectator*, 12th June.

Flynn, N.J., Snook, D.L., Wade, A.J., Jarvie, H.P. (2002). Macrophyte and periphyton dynamics in a UK Cretaceous chalk stream: the River Kennet, a tributary of the Thames. *Science of the Total Environment* **282-283**, 143-157.

Franklin, P., Dunbar, M., Whitehead, P. (2008). Flow controls on lowland river macrophytes: A review. *Science of the Total Environment* **400**, 369-378.

Garbey, C., Murphy, K.J., Thiébaut, G., Muller, S. (2004a). Variation in P-content in aquatic plant tissues offers an efficient tool for determining plant growth strategies along a resource gradient. *Freshwater Biology* **49**, 346-356.

Garbey, C., Thiébaut, G., Muller, S. (2004b). Morphological plasticity of a spreading macrophyte, *Ranunculus peltatus*, in response to environmental variables. *Plant Ecology* **173**, 125-137.

Garbey, C., Thiébaut, G., Muller, S. (2006). An experimental study of the plastic responses of *Ranunculus peltatus* Schrank to four environmental parameters. *Hydrobiologia* **570**, 41-46.

Green, J. C. (2005a). Comparison of blockage factors in modelling the resistance of channels containing submerged macrophytes. *River Research and Applications* **21**, 671-686.

Green, J. C. (2005b). Modelling flow resistance in vegetated streams: review and development of new theory. *Hydrological Processes* **19**, 1245-1259.

Green, J. C. (2005c). Velocity and turbulence distribution around lotic macrophytes. *Aquatic Ecology* **39**, 1-10.

Green, J. C. (2006). Effect of macrophyte spatial variability on channel resistance. *Advances in Water Resources* **29**, 426-438.

Glasspool, J. (2007). *Chalk Streams: A Guide to their Natural History and River Keeping.* The Test and Itchen Association Ltd., Winchester.

Grieve, N., Watson, R., Newman, J., Clark, S. (1999). *Monitoring of the Ranunculus beds in the rivers Avon, Wylye and Nadder*. English Nature, Devizes.

Grieve, N., Newman, J., Clark, S. (2000). *Monitoring of the Ranunculus beds in the rivers Avon, Bourne and Till*. English Nature, Devizes.

Gurnell, A.M., van Oosterhout, M.P., de Vlieger, B., Goodson, J. M. (2006). Reach-scale interactions between aquatic plants and physical habitat: River Frome, Dorset. *River Research and Applications* **22**, 667-680.

Halcrow Group Ltd (2004). *River Itchen Sustainability Study: Review of 'Ranunculus in Chalk Rivers'.* R & D Outputs Technical Ref: E(PR)02. Halcrow Group Ltd, Swindon.

Harrison, S.S.C. (2000). The importance of aquatic margins to invertebrates in English chalk streams. *Archiv für Hydrobiologie* **149**, 213-240.

Harrison, S.S.C., Harris, I.T. (2002). The effects of bankside management on chalk stream invertebrate communities. *Freshwater Biology* **47**, 2233-2245.

Haslam, S.M., Sinker, C.A., Wolseley, P.A. (1975). British Water Plants. *Field Studies* **4**, 243-351.

Haslam, S.M. (2006). River plants: the macrophytic vegetation of watercourses, 2nd Edition. Forrest Text, Cardigan.

Hatton-Ellis, T.W., Grieve, N. (2003). *Ecology of Watercourses Characterised by* Ranunculion fluitantis *and* Callitricho-Batrachion *Vegetation.* Conserving Natura 2000 Rivers Ecology Series No. 11. English Nature, Peterborough.

Hearne, J.W., Armitage, P.D. (1993). Implications of the annual macrophyte growth-cycle on habitat in rivers. *Regulated Rivers Research and Management* **8**, 313-322.

Heppell, C. M., Wharton, G., Cotton, J.A.C., Bass, J.A.B., Roberts, S.E. (2009). Sediment storage in the shallow hyporheic of lowland vegetated river reaches. *Hydrological Processes* **23**, 2239-2251.

Heywood, M.J.T., Walling, D.E. (2003). Suspended sediment fluxes in chalk streams in the Hampshire Avon catchment, U.K. *Hydrobiologia* **494**, 111-117.

Holmes, N.T.H. (1999). Recovery of headwater stream flora following the 1989-1992 groundwater drought. *Hydrological Processes* **13**, 341-354.

Holmes, N.T.H., Boon, P., Rowell, T. (1999). *Vegetation communities of British rivers: A revised classification.* Joint Nature Conservation Committee, Peterborough.

Holmes, N. (2010). Chapter 12: The Development and Application of Mean Trophic Rank (MTR). *In*: Hurford, C., Schneider, M., Cowx, I. (ed.). *Conservation Monitoring in Freshwater Habitats: A Practical Guide and Case Studies*. Springer, London, UK.

House, A. (unpublished). *Review of factors determining Ranunculus distribution on the Wylye and Hampshire Avon, Wiltshire.* Wessex Water, Bath.

Jarvie, H.P., Lycett, E., Neal, C., Love, A. (2002a). Patterns in nutrient concentrations and biological quality indices across the upper Thames river basin, UK. *Science of the Total Environment* **282-283**, 263-294.

Jarvie, H. P., Neal, C., Williams, R. J., Neal, M., Wickham, H. D., Hill, L. K., Wade, A. J., Warwick, A., White, J. (2002b). Phosphorus sources, speciation and dynamics in the lowland eutrophic River Kennet, UK. *Science of the Total Environment* **282-283**, 175-203.

Jarvie, H.P., Neal, C., Williams, R.J. (2004). Assessing changes in phosphorus concentrations in relation to in-stream plant ecology in lowland permeable catchments: bringing ecosystem functioning into water quality monitoring. *Water, Air and Soil Pollution* **4**, 641-655.

Jarvie, H.P., Neal, C., Jurgens, M.D., Sutton, E.J., Neal, M., Wickham, H.D., Hill, L.K., Harman, S.A., Davies, J.J.L., Warwick, A., Barret, C., Griffiths, J., Binley, A., Swannick, N., McIntyre, N. (2006). Within-river nutrient processing in Chalk streams: The Pang and Lambourn, UK. *Journal of Hydrology* **330**, 101-125.

Knapton, R.W., Petrie, S.A. (1999). Changes in distribution and abundance of submerged macrophytes in Long Point's Inner Bay, Lake Erie: implications for foraging waterfowl. *Journal of Great Lakes Research* **25**, 783-798.

Köhler, J., Hachol, J., Hilt, S. (2010). Regulation of submersed macrophyte biomass in a temperate lowland river: Interactions between shading by bank vegetation, epiphyton and water turbidity. *Aquatic Botany* **92**, 129-136.

Lansdown, R.V. (2007). The Identity of *Ranunculus* subgenus *Batrachium* in the River Itchen. Environment Agency: Southern Region.

Lansdown, R.V. (2009). Monitoring the Vegetation of the River Itchen. Report for the Environment Agency Southern Region.

Machata-Wenninger, C., Janauer, G.A. (1991). The measurements of current velocities in macrophyte beds. *Aquatic Botany* **39**, 221-230.

Madsen, J.D., Chambers, P.A., James, W.F., Koch, E.W., Westlake, D.F. (2001). The interaction between water movement, sediment dynamics and submersed macrophytes. *Hydrobiologia* **444**, 71-84.

Madsen, T.V., Cedergreen, N. (2002). Sources of nutrients to rooted submerged macrophytes growing in a nutrient-rich stream. *Freshwater Biology* **47**, 283-291.

Mainstone, C., Holmes, N.T., Armitage, P.D., Wilson, A.M., Marchant, J.H., Evans. K., Solomon, D. (1999). Chalk rivers - nature conservation and management. Report produced on behalf of English Nature and the Environment Agency. *FIN/8. 16/97-8.*

Mony, C., Thiébaut, G., Muller, S. (2007). Changes in morphological and physiological traits of the freshwater plant *Ranunculus peltatus* with the phosphorus bioavailability. *Plant Ecology* **191**, 109-118.

Newall, A.M., Hughes, J.M.R. (1995). Microflow environments of aquatic plants in flowing water wetlands. In: Hughes, J.M.R., Heathwaite, A.L. (ed.): *Hydrology and Hydrochemistry of British Wetlands*. John Wiley and Sons Ltd, Chichester, UK.

Newbold, C., Mountford, O. (1997). *Water level requirements of wetland plants and animals*. English Nature, No. 5.

Newman, J.R., Raven, J.A. (1999). CO_2 is the main inorganic species entering photosynthetically active leaf protoplasts of the freshwater macrophyte *Ranunculus penicillatus* ssp. *pseudofluitans*. *Plant, Cell & Environment* **22**, 1019-1026.

O’Hare, M.T., Hutchinson, K.A., Clarke, R.T. (2007a). The drag and reconfiguration experienced by five macrophytes from a lowland river. *Aquatic Botany* **86**, 253-259.

O’Hare, M.T., Stillman, R.A., McDonnell, J., Wood, L. (2007b). The effects of mute swan grazing on a keystone macrophyte. *Freshwater Biology* **52**, 2463-2475.

O’Hare, M.T., Clarke, R.T., Bowes, M.J. Cailes, C., Henville, P., Bisset, N., McGahey, C., Neal, M. (2010a). Eutrophication impacts on a river macrophyte. *Aquatic Botany* **92**, 173-178.

O’Hare, M.T., McGahey, C., Bissett, N., Cailes, C., Henville, P., Scarlett, P. (2010b). Variability in roughness measurements for vegetated rivers near base flow, in England and Scotland. *Journal of Hydrology* **385**, 361-370.

Palmer-Felgate, E.J., Jarvie, H.P., Williams, R.J., Mortimer, R.J.G., Loewenthal, M., Neal, C. (2008). Phosphorus dynamics and productivity in a sewage-impacted lowland chalk stream. *Journal of Hydrology* **351**, 87-97.

Pedersen, T.C.M., Baattrup-Pedersen, A., Madsen, T.V. (2006). Effects of stream restoration and management on plant communities in lowland streams. *Freshwater Biology* **51**, 161-179.

Porteus, T.A., Short, M.J., Reynolds, J.C., Stubbing, D.N., Richardson, S.M., Aebischer, N.J. (2011). The impact of grazing by mute swans (*Cygnus olor*) on the biomass of chalkstream macrophytes. Game and Wildlife Conservation Trust, Fordingbridge, Hampshire.

Preston, C.D., Pearman, D.A., Dines, T.D. (2002). *New atlas of the British and Irish flora. An atlas of the vascular plants of Britain, Ireland, the Isle of Man and the Channel Islands.* Oxford University Press, Oxford.

Pulteney, R. (1800). Observations of the economical use of the *Ranunculus aquatilis;* with introductory remarks on the acrimonious and poisonous quality of some of the English species of that genus. *Philosophical Magazine Series 1* **6**, 210-215.

Rich, T.C.G., Jermy, A.C. (1998). *Plant Crib*. Botanical Society of the British Isles, London, UK.

Riis, T., Sand-Jensen, K. (2006). Dispersal of plant fragments in small streams. *Freshwater Biology* **51**, 274-286.

Riis, T., Madsen, T.V., Sennels, R.S.H. (2009a). Regeneration, colonisation and growth rates of allofragments in four common stream plants. *Aquatic Botany* **90**, 209-212.

Riis, T., Schultz, R., Olsen, H-M., Katborg, C.K. (2009b). Transplanting macrophytes to rehabilitate streams: experience and recommendations. *Aquatic Ecology* **43**, 935-942.

Riley, W.D., Pawson, M.G., Quayle, V., Ives, M.J. (2009). The effects of stream canopy management on macroinvertebrate communities and juvenile salmonid production in a chalk stream. *Fisheries Management and Ecology* **16**, 100-111.

Rodwell, J.S. (1995). *British Plant Communities, Volume 4. Aquatic Communities, Swamps and Tall-fen Herbs.* Cambridge University Press, Cambridge.

Sanders, I.A., Heppell, C.M., Cotton, J.A., Wharton, G., Hildrew, A.G., Flowers, E.J., Trimmer, M. (2007). Emission of methane from chalk streams has potential implications for agricultural practices. *Freshwater Biology* **52**, 1176-1186.

Sand-Jensen, K. (1998): Influence of submerged macrophytes on sediment composition and near-bed flow in lowland streams. *Freshwater Biology* **39**, 663-679.

Sear, D.A., Armitage, P.D., Dawson, F.H. (1999). Groundwater dominated rivers. *Hydrological Processes* **13**, 255-276.

Spink, A.J. (1992). *The Ecological Strategies of Aquatic Ranunculus Species*. PhD Thesis, Glasgow University, UK.

Spink, A.J., Murphy, K.J., Westlake, D.F. (1997). Distribution and environmental regulation of species of *Ranunculus* subgenus *Batrachium* in British rivers. *Archiv für Hydrobiologie* **139**, 509-525.

Trimmer, M., Sanders, I.A., Heppell, C.M. (2009). Carbon and nitrogen cycling in a vegetated lowland chalk river impacted by sediment. *Hydrological Processes* **23**, 2225-2238.

Wade, A.J., Whitehead, P.G., Hornberger, G.M., Jarvie, H.P., Flynn, N. (2002). On modelling the impacts of phosphorus stripping at sewage works on in-stream phosphorus and macrophyte/epiphyte dynamics: a case study for the River Kennet. *Science of the Total Environment* **282-283**, 395-415.

Walling, D.E., Collins, A.L., Jones, P.A., Leeks, G.J.L., Old, G. (2006). Establishing fine-grained sediment budgets for the Pang and Lambourn LOCAR catchments, UK. *Journal of Hydrology* **330**, 126-141.

Warren, L.L., Wotton, R.S., Wharton, G., Bass, J.A.B, Cotton, J.A. (2009). The transport of fine particulate organic matter in vegetated chalk streams. *Ecohydrology* **2**, 480-491.

Westlake, D.F. (1967). Some effects of low velocity currents on the metabolism of aquatic macrophytes. *Journal of Experimental Biology* **18**, 187-205.

Westlake, D.F. (1981). *Temporal changes in aquatic macrophytes and their environment.* Dynamique de Populations et Qualite' de L'Eau, Paris.

Westwood, C.G., Teeuw, R.M., Wade, P.M., Holmes, N.T.H., Guyard, P. (2006). Influences of environmental conditions on macrophyte communities in drought-affected headwater streams. *River Research and Applications* **22**, 703-726.

Wharton, G., Cotton, J.A., Wotton, R.S., Bass, J.A.B., Heppell, C.M., Trimmer, M., Sanders, I.A., Warren, L.L. (2006). Macrophytes and suspension feeding invertebrates modify flows and fine sediments in the Frome and Piddle catchments, Dorset (UK). *Journal of Hydrology* **330**, 171-184.

Wheeldon, J. (2003). *River Avon cSAC Conservation Strategy*. English Nature, Peterborough.

Wilby, R. (1996): *Modelling Macrophyte Status in Hampshire Streams*. Loughborough Ecologists, Unpublished Interim Report for the National Rivers Authority.

Willby, N., Pitt, J.A., Phillips, G. (2009). *The ecological classification of UK rivers using aquatic macrophytes*. UK Environment Agency Science Reports. Project SC010080/SR.

Wright, J.F., Gunn, R.J.M., Winder, J.M., Wiggers, R., Vowles, K., Clarke, R.T., Harris, I. (2002). A comparison of the macrophyte cover and macroinvertebrate fauna at three sites on the River Kennet in the mid 1970s and late 1990s. *Science of the Total Environment* **282-283**, 121-142.

Wright, J.F., Clarke, R.T., Gun, R.J.M., Winder, J.M., Kneebone, N.T. Davy-Bowker, J. (2003). Response of flora and macroinvertebrate fauna of a chalk stream site to changes in management. *Freshwater Biology* **48**, 894-911.

Wright, J.F., Clarke, R.T., Gunn, R.J.M., Kneebone, N.T., Davy-Bowker, J. (2004). Impact of major changes in flow regime on the macroinvertebrate assemblages of four chalk stream sites, 1997-2001. *River Research and Applications* **20**, 775-794.

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GLOSSARY OF ABBREVIATIONS

agg. - agglomerate

spp. - species

ssp. - subspecies

var. - variety

TAXON INDEX

This index is hoped to provide a quick, at-a-glance tool for identifying the species named in this study. Page numbers are given for reference to its use in the text. Only taxa at species level have their associated page numbers shown.

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