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Agricultural Ecology Research: Its role in delivering sustainable farm systems

Sustainable farming in an upland water catchment

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Summary

Agricultural and ecological data from the Loweswater catchment in the English Lake District was collected to provide evidence as part of a community catchment management initiative (the Loweswater Care Project LCP) taking place under the remit of the Rural Economy and Land Use (RELU) programme. Agro-ecological data collected in conjunction with the LCP included; catchment mapping, vegetation sampling, farm management and economy interviews, lake sampling and hydrological modelling. Despite the importance of farming for the maintenance of culturally important landscapes at Loweswater, its' sustainability is under threat from declines in farmer numbers and profitability. The environmental sustainability of remaining farming systems is at risk from current and historically recent management practices. However, the research highlighted how improved management practices could help to enhance sustainability through reduced impact on water quality and how policy measures could help to enhance both profitability and environmental sustainability. This case study highlights the role of agro-ecological research for sustainable farm management at a catchment scale.

Key words: Catchment management, interdisciplinary, agri-environment, management practices

Introduction

Apparent and toxic blue-green algal blooms at Loweswater in the late 1990's (Maberly *et al*., 2006) were a cause for concern for farmers and locals including the lake owners and managers of land in the catchment, the National Trust. In 2000, the EC Water Framework Directive (WFD) sought to introduce a national audit of water quality focused on ecology and chemistry which was designed to enable the relevant government bodies (the Environment Agency, EA, in England and Wales) to achieve objectives of 'good ecological status' and 'good chemical status' for waterbodies by 2015 (European Union, 2000). Farmers play a key role in land management in rural catchments in the UK. Their activities have the potential to impact negatively upon water quality and include field applications of nutrients (fertilisers, manures, animal feed, etc), pesticide usage, or the inappropriate storage of animal feed or waste (Haygarth, 2005; Heathwaite & Johnes 1996). Additionally, farmers and other householders in rural areas are heavily dependent upon septic tanks to deal with human waste and these are increasingly being recognised as having potentially serious impacts on water quality (May *et al*., 2010). At Loweswater the response of farmers under threat of EA prosecution in 2001 was to make an active and co-ordinated response to the water quality problem, which included engaging with scientists to begin to try and understand the causes of the algal blooms. This kind of approach had been advocated by the SLIM (Social Learning for the Integrated Management)

Project (Blackmore *et al*., 2007) which highlighted the need for science to become part of a more integrated approach to the management of water catchments.

The RELU project (2007–2010), under which the research described in this paper was conducted, built on the willingness of farmers in the catchment to work together, and with scientists, and further broadened out both the approach and the stakeholder community to reflect the many interacting factors potentially impacting on water quality. This was a very different kind of research project in which the social, economic and ecological roles of agriculture and those practising it were all considered alongside the potential impacts of other catchment residents. As well as being interdisciplinary, the research was also conducted through an active mechanism, self named the Loweswater Care Project (LCP). The mission statement of the LCP agreed in 2008 reads: 'The Loweswater Care Project (LCP) is a grassroots organisation made up of local residents, businesses, farmers, ecologists, sociologists, agronomists, environmental agencies and other interested parties. We work collectively to identify and address catchment-level problems in an inclusive and open manner. The LCP's vision is to gain a better understanding of the diverse challenges faced by the Loweswater catchment and together to seek economically, socially and ecologically viable ways forward and put them into practice.' An important tenet of the project was its inclusivity; it both acknowledged complexity and embraced a breadth of different forms of knowledge and expertise, recognising the potential limitations of more prescriptive approaches.

The agri-environment aspects of the research adopted this approach so that understanding the agro-ecology of the catchment encompassed the farming system itself, its' impacts on the landscape (both land and water) and its' social and economic dimensions within the catchment. It incorporated data from a range of sources and of different types and sought to ensure that the research carried out provided answers where possible and potential solutions where practicable.

Methods

Site description

Loweswater is a small lake (0.64 km) within a largely upland rural catchment (7.6 km) in the Northwest of England. The water catchment forms a bowl around the lake with steep slopes to the north-east and south-west of the lake and shallower more productive land at either end. The primary land uses in the catchment, apart from residential buildings, are farming and tourism. Eight farms manage almost all of the land that falls within the Loweswater catchment boundary. Previous work on Loweswater indicated that phosphorus (P) is probably the main nutrient controlling phytoplankton production in Loweswater (*i.e.* the 'limiting' nutrient) (Maberly *et al*., 2006).

Catchment mapping

For the purposes of this study the Loweswater catchment area was initially defined using Ordnance Survey (OS) data and expert judgement as to likely direction of water flow from land surrounding Loweswater. The catchment boundary (watershed) was further ground-truthed during survey work in the catchment and following discussion with catchment residents with expert local knowledge on the direction of drainage from particular land parcels at the margins of the catchment.

The Loweswater catchment was digitally mapped using a geo-referenced, hand-held, geographical information system (GIS) that had been developed for the UK Countryside Survey 2007 (Carey, 2008). Mapping was based on underlying Ordnance Survey MasterMap, and data for polygons, linear and point features was collected. Each polygon, line or point was assigned a Broad or Priority Habitat[1], vegetation type, linear or point feature type as per Countryside Survey (CS) methodologies (Carey, 2008). Catchment data on habitats was used in the catchment modelling (investigating impacts of land management on lake water quality) as described below. These required aggregating areas of vegetation types/habitats measured in the field to provide areas of habitat types with phosphorus export co-efficients using the scientific literature (see Maberly *et al*., 2006). Mapped

[1]The Joint Nature Conservancy Council www.jncc.gov.uk

data was also transferred to standard Farm Environmental Record (FER's) maps as provided by Natural England for farmers applying for entry into Environmental Stewardship[2]. FER's are highly compatible with the CS recording system, both based on OS polygon data enabling recording on area, linear and point features. Resulting maps were discussed, by farm, with the NE officer with responsibility for the administration of agri-environment schemes at Loweswater. Basic analyses were carried out to investigate linear features within the catchment at a farm level.

Large vegetation plots (200 m^2) were sampled across the catchment, again using CS methodology (Carey, 2008). Species presence and cover were recorded within a set of nested quadrats.

Farm management

Each of the farmers managing land in the catchment was interviewed by a local agricultural consultant. Farmers were questioned on all aspects of their farming activities within the catchment, including: land area and usage; livestock management; import or export of nutrients in the form of fertilisers, manure/slurry, silage and bought in feedstuffs; and farm income including single farm payments and membership of agri-environment schemes. The use of expert elicitation considerably enhanced the quality and depth of data obtained. In order to obtain information on soil P status on agricultural land in the catchment, soil samples from similarly managed groups of high production grassland fields across all farms were taken by the consultant agronomist. These were then analysed for phosphorus content using standard agricultural soil analysis techniques (Defra, 2010). The phosphorus requirement (P deficit) of each group of fields was then calculated from this information, taking into account the corresponding land use (Rockliffe, 2009). A total farm soil P deficit was calculated by summing values for each group of fields across the farm.

Historical information

During the course of the project the LCP approved a number of small projects from a fund specifically allocated for the purpose by the funders. This project built on evidence previously collected in and around the Loweswater area including more detailed investigation of a lake sediment core taken in Loweswater in 2000 (Bennion, 2000) and historical information on land management collected by Professor Angus Winchester[3]. The small project sought to reconcile the two data sources to see whether the lake sediment data reflected management changes in the catchment.

Water quality monitoring

An automatic monitoring buoy was situated on the lake between 2007 and 2010. This provided data for use in a water quality modelling exercise aimed at linking land use to water quality. This data included variation in water temperature with depth. Monthly samples collected during limnological surveys also provided data on phytoplankton abundance expressed as chlorophyll *a* concentration (the main photosynthetic pigment), concentrations of key nutrients (*i.e.* soluble reactive phosphorus, nitrate and silicate) and phytoplankton composition and abundance. Water samples were based on an integrated sample collected from the upper 5 m of the water column.

Weather and hydrological data

Daily rainfall data were compiled from records kept by a local resident and an automatic rain gauge at the southern end of the lake. The water quality monitoring station (above) included a weather station which provided daily data on wind speed, air temperature and relative humidity. As measured discharge values for Loweswater were not available for the lake monitoring period, discharge was estimated by averaging the simulated discharge values for the nearby outflows from the Park Beck data and those simulated from the Scale Hill data. A small LCP project was commissioned to investigate catchment hydrogeomorphology (Haycock, 2010).

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[2]http://www.naturalengland.org.uk/ourwork/farming/funding/es/els/default.aspx

[3]See http://www.lancs.ac.uk/fass/projects/loweswater/noticeboard.htm, 3rd LCP meeting 'Counting sheep: a thousand years of farming and land use change in Loweswater'.

Septic tank data

The septic tank data was collected as part of one of the small LCP projects referred to above (see *Historical information*). A key issue which the LCP wanted to see tackled was the potential loss of phosphorus from septic tanks to the lake. An expert on waste management living within the catchment proposed and carried out work to identify the number and location of septic tanks within the catchment as well as their condition, number of users, detergent usage and level of management. Calculating the P losses from these systems involved the use of published data on average P levels in human waste and actual information on P levels in the detergents used by specific households. Expert opinion was used to estimate the level of P retention within each type of septic tank. Exports from septic tanks as both point and diffuse sources were included in the modelling described below.

Modelling

A series of linked models were used to assess P runoff from the catchment to the lake and its impact on water quality (Fig. 1) (current scenario) and to test potential change scenarios. Models were linked in the sense that the outputs from one fed into the next, so that farm nutrient budget information fed into the runoff model and nutrient outputs from the runoff model fed into the algal production model. Both the runoff model and the algal model also required other data as outlined above. Detailed modeling methodology is described in Norton *et al*. (2011). The models used included the ADAS Planning Land Applications of Nutrients for Efficiency and the environment (PLANET) farm nutrient budgeting model, the Generalized Watershed Loading Function (GWLF) model, a standard hydrological catchment model and Phytoplankton RespOnses To Environmental Change (PROTECH), a lake algal model. PLANET was selected on the advice of the agricultural consultant used to collect the farm management data and because of its wide availability and use by farmers. Changes scenarios used included: a 'woodland' scenario; a 'natural grassland' scenario with no inputs or livestock; a 'no cattle', double sheep scenario; and a 'double cattle', half sheep scenario.

Results

Key features:

- The Loweswater catchment consisted of a mix of 13 Broad Habitats, 48% of which were upland Broad Habitats. Agricultural grasslands together with (a very small area of) arable land constituted 37% of the catchment area with 13% woodland and 2% Buildings and Gardens.
- Land in the catchment was mainly used for beef cattle and lamb production with the majority of the agricultural grassland within catchment used for grazing; only a small proportion was used for silage or hay production. Upland areas (fells) were grazed predominantly by sheep.
- Six out of the eight farmers were applying surplus potassium and three out of eight were applying surplus phosphorus. P indices were, as expected, highest on arable land and on silage land.
- The catchment contained approximately 150 km of linear features which varied between farms. 70% of walls were recorded as in good condition. The length of lines of trees in the catchment was double the length of managed hedges. Many lines of trees were evidently formerly managed as hedges. Linear regression analysis investigating the relationship between the length of lines of trees and the amount of inbye (improved land near farm buildings) managed by a farmer showed that, unlike hedges (Fig 2a), the more land managed the greater the length of lines of trees (Fig. 2b; $R^2 = 0.52$, n=8, $P < 0.05$).
- There were around 500 individual trees, many of which were well established, standing singly (including some in hedges) or in small clumps around the catchment.

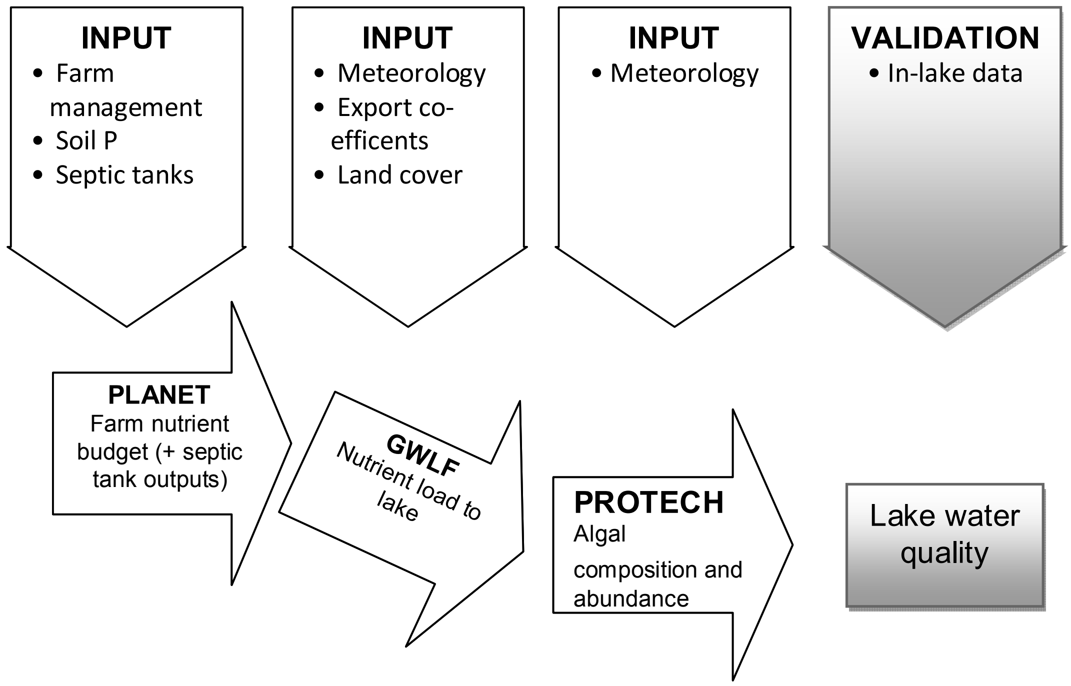

Fig. 1. Schematic of linked models and driving data used to describe the impacts of land management and septic tank use on lake water quality.

- Vegetation plots were of comparable species richness for Broad Habitats in similar landscapes using the CS land classification, see Bunce *et al.*, 1996). Regression analysis revealed that there was no relationship between species richness of plots and field soil P index.
- The majority of the eight farmers managing land in the catchment were over 50 years old, with three having descendents who would potentially take on the farm after their retirement.
- Historically all farmland has been included in the Environmentally Sensitive Area's (ESA) scheme with farmers having entered the scheme between 1993 and 1996. Land on six holdings will continue to be under ESA prescriptions until between 2012 and 2014 (two 10 year agreements, dependent on starting date).
- Discussions with Natural England over Farm Environmental Records revealed that all farmers were at least eligible for entry into the Entry Level Scheme on the basis of farm management practices and features on the farms (*e.g.* walls, hedges, in-field trees). This led to two farmers successfully applying for ELS/UELS and HLS entry during the course of the project. Discussions also explored the potential for a joint catchment Higher Level Scheme application to protect the lake, watercourses into the lake and wet areas at the lake in-flow. It is proposed that this is re-visited as ESA schemes on many of the farms finish in the next 2 years.
- Income from the traditional agricultural sources amounted to as little as 32% of total income at one extreme, and as much as 58% at the other end of the scale, with 50% being a 'typical' figure, in line with similar farms in the North West. Total farming profit was on average £7,000. In order to improve business sustainability a number of the farmers have developed diversification enterprises in the past – contracting, Bed & Breakfast accommodation and camping barns for example.
- Historical research revealed marked agricultural change in two periods which could be matched to marked changes in lake sediments indicating deterioration in condition. These were during the mid 19th century with the advent of liming and tile drainage and again between 1945 and 1965 as tractors replaced horses, pastoral land replaced arable and there was a three fold increase in nitrate use.

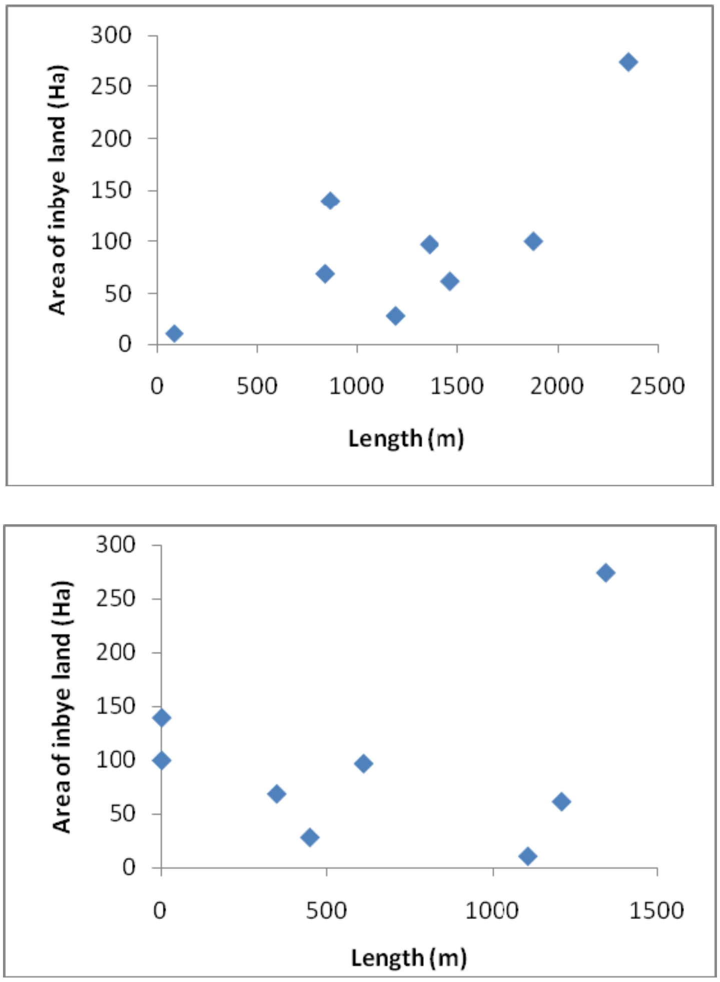

Fig.2. Relation between area of inbye land and length of a) lines of trees and b) managed hedges.

- The number of farmers working land in the catchment has reduced from 22 in 1941 to the present number of eight. Current livestock (sheep and cattle) may be only as much a half of numbers recorded in 1941.
- The only washing product contributing to phosphorus levels in sewerage at Loweswater was dishwasher detergent at a maximum of 5% of total P loads. A range of different septic tank facilities across the catchment resulted in different losses of P to water.
- Catchment hydrology was heavily influenced by historical human land use, with straightened channels and high banked streams common on inbye land from which water flowed into the lake.
- The lake has a long retention time, *i.e.* water entering the lake takes up to 200 days to leave it.

Modelling

- PLANET indicated that most farms were generating a P deficit, with only one farm generating a surplus. The total loss of P from improved grassland in the catchment was equivalent to 0.56 kg ha^{-1} yr^{-1} (197 kg P yr^{-1}).
- Comparatively the loss of P from septic tanks was low. Septic tanks modelled as diffuse sources contributed little to the P loads from farmland and as point sources increased loads by 33 kg yr^{-1} across the whole catchment.
- Models linking farm management, land use, hydrology and using meteorological data from the monitoring buoy and land-use data were run for the current conditions and possible future scenarios of land-use.

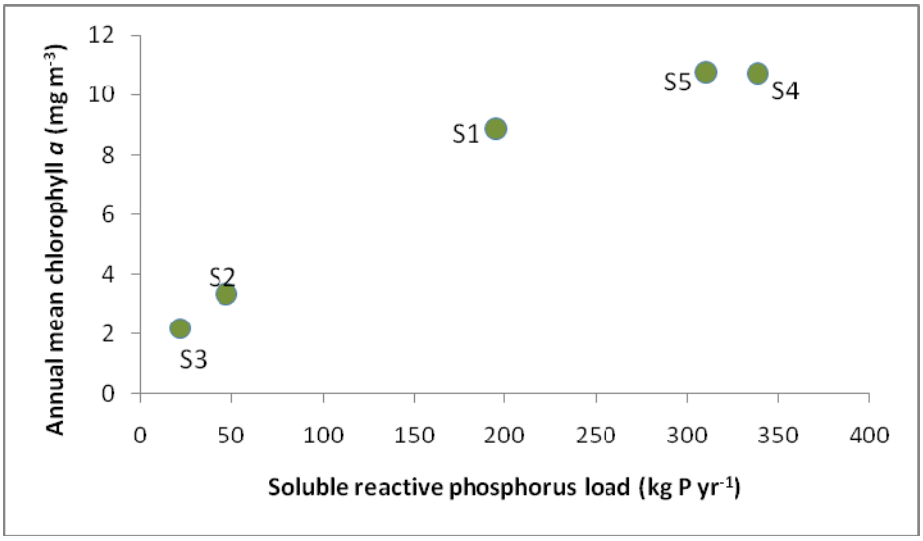

Fig. 3. Annual mean in-lake total chlorophyll *a* concentrations resulting from changes in the soluble reactive (bioavailable) phosphorus (P) load to the lake under the various catchment management scenarios. S1 –'current conditions', S2 – 'woodland', S3 – 'natural grassland', S4 – 'no cattle', S5 – 'double cattle'.

- The predicted annual mean in-lake chlorophyll *a* concentration of 8.9 mg m^{-3} from the linked models accorded well with the observed annual means for 2008 and 2009, *i.e.* 9.0 mg chlorophyll *a* m^{-3} and 9.6 mg chlorophyll *a* m^{-3}, respectively.
- The results of running PROTECH for the different catchment management scenarios are presented as annual mean concentrations of total chlorophyll a (Fig. 3). Some scenarios produced very different results to those for current conditions.
- The 'woodland' (S2) and 'natural grassland' (S3) scenarios show very low levels of P input to the lake predicting a sharp decline in chlorophyll *a*. The 'no cattle' (S4) and 'double cattle' (S5) scenarios produced a much smaller change suggesting that factors other than P (light or other nutrients) may restrict phytoplankton production under these conditions.
- The relationship between annual mean total algal chlorophyll *a* and total annual mean load of SRP followed a regular pattern and so can be used to estimate the response of the lake to other SRP loads generated by different land use scenarios (Fig. 3). This response was best described by a logarithmic curve ($y = 3.63\ln(x) - 9.89$, $R^2 = 0.97$, $P < 0.001$)

Discussion

Agro-ecology is a broad church and the work carried out at Loweswater may be perceived as both a little parochial and somewhat marginal in comparison to, for example, replicated experiments or multi-site surveys. However, in seeking to understand the many interacting aspects of the relationship between farmers and the catchment and becoming involved with an active process of catchment management a great deal has been learnt about farming and ecology and action has been taken to improve the sustainability of the catchment.

Clearly, humans have been impacting on the catchment for hundreds of years, as evidenced through the historical data collected for the catchment and the lake. Significant changes to the algal community have resulted from major alterations to catchment hydrology in the past, including tile drainage, stream channelisation and dredging. More recently agricultural inputs and the use of tractors have also made their mark. From a human perspective, farming in the catchment has also had its benefits. The complex matrix of habitats across the catchment, the presence of hedges and walls and farm buildings have provided not only a place to live and work but also a place of great scenic beauty that others want to live in and visit. As the foot and mouth outbreak in 2001 showed, for farmers, and for the wider community in such areas, tourism economically underpins the landscape. For several farmers at Loweswater, tourism directly affects income; farming on its own is barely economically sustainable. Currently economic viability in the catchment is heavily dependent on the Single Farm Payment and agri-environment scheme payments. This research has helped to endorse the important role that such schemes pay in agriculturally marginal areas in terms of maintaining farmers in their role, *i.e.* economic sustainability.

The research indicated that current management practices have a negative impact on the ecological sustainability of the catchment in terms of impacting on lake water quality. This is exacerbated by the lake's long retention time. In general agricultural practices in the catchment are of low intensity, but algal blooms in the lake can be linked to P loss from agricultural land in the catchment. Septic tanks also contribute to P loss but to a lesser extent. The farm nutrient budget model found that P loss may be primarily due to a surplus on one farm. Although the total P loss fitted well to lake algal concentrations it seems unlikely that only one farm was contributing to P loss, but rather that losses from several sources in the catchment contributed to the total. When the results were reported to the farmers and community, awareness of potential sources was raised at the same time so that all catchment residents could take action where relevant. The particular farmer with the surplus was happy to alter practices from both an economic and an environmental perspective.

This research does not provide evidence for role of agri-environment schemes in terms of ecological sustainability. Those farmers entering into the Entry Level Scheme on the back of the research were able to do so with very little change to their management practices. Notably, with a lack of capital works funding under ELS farmers are not currently able to improve deteriorating features, such as walls and hedges, as they were, for example under the Environmentally Sensitive Areas scheme. This research indicates that increases in the areas managed by farmers, as a result of decreases in farm number may be having a negative impact on the management of hedges, leading to their deterioration into lines of trees. The potential co-operative catchment Higher Level Scheme proposed by Natural England may help to ensure more active catchment management aimed at improving water quality, conserving high quality habitats and habitat structure as well as the economic viability of farming (since payments under the Higher Level Scheme exceed those under Entry Level).

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