Integrating multi-scale data to model the relationship between food resources, waterbird distribution and human activities in freshwater systems: preliminary findings and potential uses

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Understanding and predicting the likely consequences of anthropogenic disturbance on species and ecosystems is a major prerequisite of achieving the sustainable use of natural resources. It is also a key element in the management of sites with statutory designation. During planning and decision-making processes involving potential disturbance issues, land managers and responsible authorities are often required to take account of the needs and views of a diversity of site user groups. The effects and impacts of disturbance can occur over a range of spatial and temporal scales, and research into these consequences must address this problem. This paper provides (1) an overview of the field and analytical methodologies contributing to the development of an integrated method for collecting multi-scale bird, resource and disturbance data in freshwater systems, and (2) an overview of the drivers and need for such data in sustainable resource management. Whilst the results of the bird–habitat–disturbance modelling arising from these data will be published elsewhere, the types of information that will be generated are illustrated and their potential use within planning and decision-making processes discussed.

Compared with much of northern and central continental Europe, the UK has a relatively mild winter climate, and a broad range of normally ice-free aquatic habitats. These conditions attract large numbers of wintering waterbirds, and more than 200 sites in the UK are currently of international importance for one or more species of waterbirds, and over 50 regularly hold more than 20 000 birds (Collier *et al.* 2005). Some waterbird groups, particularly diving and dabbling ducks, extensively utilize freshwater habitats during the winter, including lakes, rivers, canals, ponds and gravel pits. The vast majority of these sites have been (or are currently) subjected to some degree of anthropogenic modification, and indeed many are entirely artificial (Yallop *et al.* 2004). As well as being used by wintering waterbirds, UK freshwater sites are also utilized by humans for an extremely wide range of recreational activities. A survey in England and Wales showed that 14% of all countryside visits are made to inland waters, over 3 million people participate in angling, and over 5 million participate in sailing, motor boating, windsurfing or rowing (Brighton University 2002). These activities, coupled with changes in patterns of urbanization and wider countryside access since the 1960s, have resulted in conflicts of interest between humans and wildlife at many freshwater sites (Watmough 1983, Ward 1990, Hill *et al.* 1997, Robinson & Pollitt 2002). Finding a resolution to these issues has been complicated by the large number of stakeholder groups and responsible agencies involved in managing sites and protecting their wildlife interest, as well as the technical and practical difficulties of undertaking research in aquatic systems (Valley *et al.* 2005). To support management and planning at individual sites, there is a substantial framework of statutory instruments and non-statutory agreements aimed at ensuring the sustainable use of wetlands resources and the maintenance of their biodiversity (O'Connell 2000, O'Connell & Yallop 2002). A comprehensive review of waterbirds and recreational disturbance has been published by Kirby *et al.* (2004), who also categorized the types of conflicts that can occur at freshwater sites associated with recreation.

In addition to the legislative framework, the management of freshwater resources has benefited from an substantial amount of research into the interactions between waterbirds and recreational activities (Ward 1990, Hill *et al.* 1997, Kirby *et al.* 2004). The outcome of such interactions can be measured as 'effects' or 'impacts'. An effect may be defined as an immediate behavioural response (e.g. cessation of feeding, moving away from a disturbance source), and this can be temporary or permanent. By contrast, an impact arises as a consequence of an effect. Impacts have implications for the fitness or survival of individuals, and are a function of the availability of alternative sites and the energetic costs of displacement (Gill *et al.* 1998, Stillman & Goss-Custard 2002, West *et al.* 2002). Impacts are difficult to measure directly through field-based research, but recent work has developed modelling techniques to evaluate potential reductions in fitness as a function of the frequency with which birds are made to fly by disturbance events (Goss-Custard *et al.* 2006). A number of methods have been used to study disturbance effects on waterbirds at freshwater sites. Some have focused on recording bird distribution and behaviour before and after disturbance 'events' (e.g. Draulans & van Vessem 1985, Bélanger & Bédard 1989, Madsen 1998a, Evans & Day 2001, 2002). However, as a result of site-related and other practical constraints, these studies often present few opportunities for replicated experimentation with switched treatments, i.e. where disturbance occurs on some sites and not others, and is then reversed in a given timeframe to contrast the observed effects (Madsen 1998b). Another approach has been to correlate changes in bird numbers to varying degrees of disturbance intensity and duration across a number of sites or patches (Tuite *et al.* 1984, Sutherland & Crockford 1993, Kershaw 2003). Again, control sites where resources and environmental conditions are similar but where no disturbance occurs can be difficult to establish with limited time, finances and human resources (Madsen 1998b).

Over the past 10 years, a number of studies have also looked at the impacts of disturbance in terms of reduced resource use at different disturbance levels (Gill *et al.* 1996, Frid & Dill 2002, Stillman & Goss-Custard 2002). In these studies, disturbance is conceptually assumed to be a 'predation risk' for individual birds, and there is thus a trade-off between the risk of predation (disturbance) and the need to exploit resources. A salient feature of this approach is the requirement to measure: (1) the distribution and behaviour of the birds; (2) the nature, intensity and duration proximity of disturbance events; and (3) the available food resources. In the context of bird disturbance in terrestrial and estuarine systems, measuring all three elements is relatively easy. Gill *et al.* (1996) for example investigated the distribution and numbers of geese feeding on crops and measured how crop consumption altered under different disturbance regimes. However, aquatic systems present a variety of practical difficulties for field research, particularly in relation to assessment of resources. For example, assessing submerged aquatic resources at analysis-relevant spatial scale and extent is a major undertaking. Established techniques to quantify macrophytes or invertebrates (e.g. grabs, sweeps, traps and grapnels) provide a general picture of species groupings and presence/absence, but these 'point' measures cannot be extrapolated to map distribution over larger areas (Maden 1993, Bain & Stevenson 1999, Yallop & O'Connell 2000, Yallop *et al.* 2004). A number of hydroacoustic methods have recently been applied to surveying submerged macrophytes. These include side-scanning sonar systems for delineating macrophyte beds (Bozzano *et al.* 1998, Moreno *et al.* 1998), and vertically aimed echo sounders for quantifying vegetation height and density (Sabol & Burczyñski 1998). Although some studies have been relatively successful in broad-scale mapping and qualitatively characterizing macrophytes within lakes (Duarte 1987, Thomas *et al.* 1990, Fortin *et al.* 1993), fine-scale quantitative assessments have been hampered by both hardware and software limitations (Winfield *et al.* in press). However, recent technological advances in hydroacoustics and global positioning systems (GPS) have resulted in considerable improvements in quantitative assessments (Sabol *et al.* 2002), and a small number of commercial systems are available.

The western end of the Thames valley in southern England is characterized by extensive surface deposits of sand and gravel, laid down at the end of the last glacial period 10 000 years BP. The Cotswold Water Park (CWP) lies across the Gloucestershire–Wiltshire border (51°40′N, 1°58′W) and comprises over 130 shallow lakes (generally < 6 m) of varying age and size created by aggregate extraction. Many of the lakes support extensive growths of macrophytes, and ten have been designated as Sites of Special Scientific Interest (SSSIs) on the basis of their plant assemblages (Lucas & Brown 1997). Many of the lakes also support large numbers of wintering waterbirds, and for several species the water park as a whole is of national importance (Collier *et al*. 2005). The extraction of sand and gravel is ongoing, and many new houses are being built around the periphery of the newly created lakes. Recreational activities occur on many lakes and there are plans for expansion over the next few years. There are therefore five main sources of disturbance of the lakes at CWP: aggregate extraction, house building, water sports, shooting and shore-based recreational activities. The planning of new structural and recreational developments at CWP and the maintenance of existing wildlife interests are regulated within a broad framework of statutory instruments and non-statutory agreements/action plans. A large number of agencies and stakeholder groups are often involved in a diversity of issues at a single lake site. These include: land and house owners, aggregate companies, recreational organizations and groups, countryside agencies, planning authorities, and conservation organizations and groups. In all of the activities and responsibilities of these stakeholders, there is a common need for information that leads to an understanding of the factors affecting waterbird distribution. The aim of our research programme was: (1) to develop practical methods for assessing actual or potential effects and impacts of disturbance, and (2) to develop spatial and temporal 'zonal' approaches to resolve conflicts of interest at individual sites. Central to these aims is a need to understand the role of aquatic food resources in determining waterbird responses to disturbance.

The study described in this paper 'integrates' data from hydroacoustic assessment with data on the distribution of wintering waterbirds (particularly diving ducks) and human activity events (disturbance). The study is being undertaken at eight lakes in the CWP to provide novel insights into: (1) the relationship between aquatic macrophytes and the physical environment within and around a lake, (2) the relationship between waterbirds and these macrophytes over time, and (3) the responses of birds to disturbance in relation to the spatio-temporal distribution of macrophytes and the presence of other birds. The predictive power of the analytical outputs (models) will ultimately be a function of the ability to explain the complex underlying interrelationships between birds, macrophytes, disturbance and landscape. Given the magnitude of such an undertaking, a 'phased' approach has been taken, with the research outlined in this paper being one element of a wider research programme. The current project primarily seeks to describe (model) relationships between birds and macrophytes and investigate how this is modified by human activity (disturbance). It has been assumed that modelling bird–resource relationships will be possible as a result of distributional association between birds and macrophytes (Stieglitz 1966, Olney 1968, Draulans 1982, Hamilton *et al*. 1994, DeLeeuw 1999, Michot & Reynolds 2000, Michot & Woodin 2004). This relationship could be positive, resulting from birds feeding on plant material and/or associated invertebrates, or a negative one in which birds are utilizing substrate areas, e.g. for feeding on chironomids. Although all species were recorded, the primary focus has been on Tufted Duck *Aythya fuligula* and Pochard *Aythya ferina*. Both species are known to take plant and animal prey, and to switch diets in response to local conditions (Olney 1968). Understanding the underlying causes of these relationships is the focus of a further study currently underway at the study site, which is also investigating macrophyte depletion by waterbirds using exclosure experiments. As a corollary to this, another project is attempting to obtain information on waterbird diets. Unfortunately, few opportunities exist at the CWP for faecal analysis or the analysis of gut content of shot birds. The new project will therefore use stable isotopes to investigate proportions of plant to animal material in diving duck diets, and will be linked to a radio-tracking study of how diving ducks utilize a range of wetland sites across the wider landscape. Lastly, data are also being collected at CWP on water chemistry, macrophyte species diversity, the presence of diatoms and periphyton, and macrophyte senescence. All of these additional studies are intended to improve our understanding of bird–habitat–disturbance relationships, and thus improve the predictive power of the output models. These studies also build on earlier work at the CWP, which investigated bird distribution and numbers in relation to lake trophic status, as well as diurnal feeding patterns of diving ducks (M.L. Yallop & M.J. O'Connell unpubl. data).

Although the modelling results will be published elsewhere, two key areas are presented in this paper: (1) an overview of the field and analytical methodologies contributing to the development of an integrated method for collecting multi-scale bird, resource and disturbance data in freshwater systems; and (2) an overview of the drivers and need for such data in sustainable resource management.

METHODS

Selection of study lakes

Permission from lake owners was granted to visit a range of sites at CWP. Ultimately, eight lakes were selected because preliminary fieldwork at CWP suggested that this was the maximum number from which two observers could practicably obtain data during a weekly cycle of observation (see below). There was also a need to ensure that it was possible to launch a boat at the site. In addition, historical bird count data from the lakes (CWP Society unpubl. data) were used to select four lakes with peak winter counts of > 200 wintering diving ducks in the last 5 years, and four with < 200. Within these two groups, sites were selected for high and low levels of anthropogenic disturbance. Of necessity, this was a subjective assessment using the extensive site knowledge of local park rangers. Figure 1 shows the distribution and relative extent of the eight selected study lakes, which were between 5 and 45 ha in size.

Mapping birds and human activity

Bird and 'disturbance event' observations were carried out for each study lake between November and March in the winters of 2004/05 and 2005/06. For the purpose of this study, all human activities ('events') were recorded in order to remove subjective views of what constitutes a disturbance to waterbirds. The number, behaviour and position of bird species on the lake surface and all terrestrial and aquatic human activity disturbance events were mapped during four 2-h periods throughout each day. Meteorological conditions were also recorded. For each of the standardized 2-h recording periods, mapping was undertaken at least once every month between October and March, and for weekdays and weekends, to contrast levels of disturbance at these times. An assessment of the ability of observers accurately to map bird positions on the lake was evaluated by observers recording the position of a survey boat undertaking hydroacoustic transects (see below, M.J. O'Connell *et al.* unpubl. data). The position of birds and disturbance events was geo-referenced and transferred to an MS Access database.

Hydroacoustic assessment of macrophytes

The field methods and equipment used for the hydroacoustic assessment of macrophytes are provided in Winfield *et al.* (in press). The sampling regime is shown in Table 1. All but two of the eight study lakes

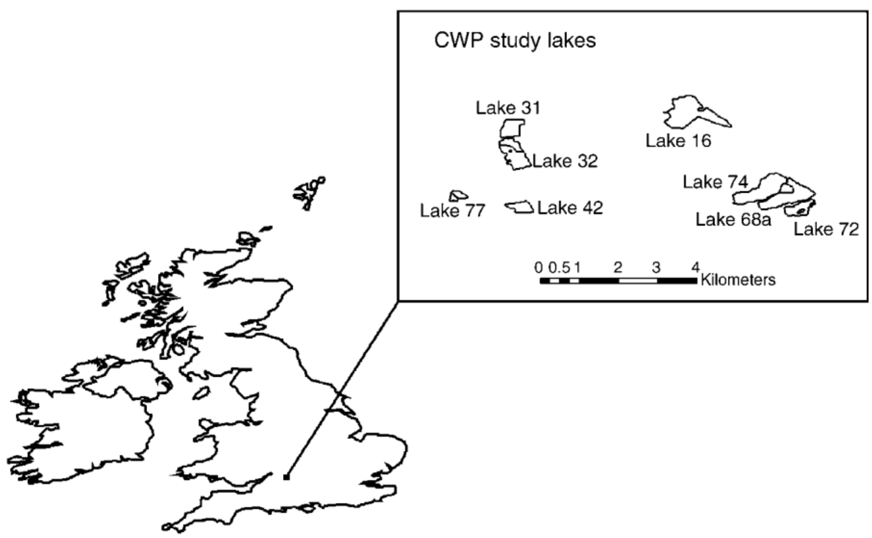

Figure 1. Location of the Cotswold Water Park and relative position and size of eight study lakes. Only those lakes studied are shown.

Table 1. Hydroacoustic sampling dates.

	2003	2004			2005			2006	
Lake	Oct.	Jan.	Apr.	Oct.	Jan.	Apr.	Aug.	Jan.	Apr.
42							✓	✓	✓
77							✓	✓	
16					✓		✓	✓	✓
31	✓	✓	✓	✓	✓	✓	✓	✓	✓
32					✓		✓	✓	✓
68a					✓		✓	✓	✓
72					✓		✓	✓	
74					✓		✓	✓	✓

were sampled four times between 2005 and 2006, the other two being sampled on three occasions. One of the sites (Lake 31) was sampled nine times between 2003 and 2006 to provide a detailed study of within- and between-season changes in macrophyte distribution.

Spatial interpolation and development of GIS

Outputs from the hydroacoustic surveys were imported into a Geographic Information System (GIS) (ArcGIS v.9.0, ESRI, Redlands, CA, USA). Using a Kriging interpolation technique developed for aquatic transect data by Valley *et al.* (2005), maps of the following information were generated for each of the eight lakes: (1) macrophyte percentage cover, depth below surface and height; and (2) water depth. Macrophyte height and percentage cover data were then used in conjunction with water depth to produce a percentage volume infestation (PVI) of the water column. All data were subsequently re-scaled within the GIS to a 25 × 25-m grid. Waterbird distribution data were then imported to each grid cell from the relational database. The number and intensity of terrestrial and aquatic human activities were also imported after rendering into an index value for each cell. The index was calculated by summing the events in all sectors divided by a cell's distance from each sector.

PRELIMINARY OUTPUTS

Figure 2 shows temporal dynamics of the percentage cover of macrophytes on Lake 31 produced by Kriging interpolation of hydroacoustic survey data. The data suggest considerable changes within years,

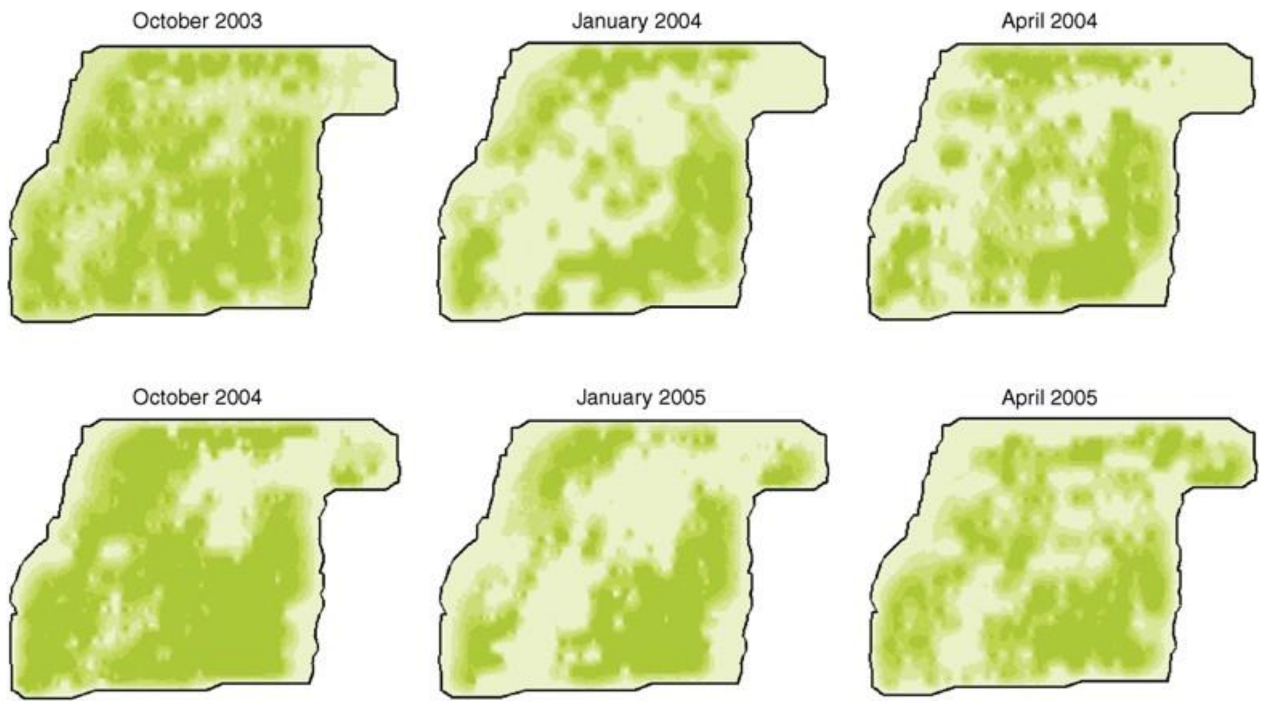

Figure 2. Within- and between-year temporal dynamics of the cover of macrophytes on Lake 31 produced by Kriging interpolation of hydroacoustic survey data. Colours represent percentage cover in five classes ranging from dark green (> 80% cover) to pale green (< 20% cover).

and that these changes are consistent between years. Further analysis will include the use of cell statistic tools within the GIS to identify the 'hotspots' of change in macrophyte cover, height, and depth in relation to bird use and disturbance.

Figure 3 shows the association between the size of feeding flocks of Tufted Duck in January and areas of high and low percentage macrophyte cover. The figure also shows the sectors in which disturbance events were recorded, and the mean number of walkers and dog-walkers per hour for each of these sections. The northwest end of the lake is screened from relatively high levels of human disturbance, and this is where the largest flock sizes and greatest number of flocks are found. This contrasts with the southern and eastern areas of the lake where macrophyte cover is high, but where there is considerable disturbance from walking (and other) activities.

DISCUSSION

The UK has no statutory instrument dealing specifically with the development and management of the recreational value of inland water sites. However, the government has published a number of policies aimed at the use of freshwaters for recreation, and in England there is a duty placed on local authorities to take the needs of recreation into account within planning policy (Department of Environment 1991, Department of Environment, Transport and the Regions 2000). Despite this, there is a lack of specific guidance for use in responding to local recreational planning applications with regard to the maintenance of site wildlife features (Brighton University 2002). The development of such guidance assumes the availability of information about the likely effects and impacts of recreational and other disturbance on biota. There has been a considerable amount of research in relation to waterbirds and disturbance, and numerous recommendations for associated site management techniques have been published (both areas comprehensively reviewed by Kirby *et al.* 2004). However, many of these techniques are based on descriptions of shorter-term behavioural responses to disturbance averaged across sites and habitats. These approaches are cost-effective and functional, and provide planning authorities and other stakeholders with useful broad-brush knowledge of how waterbirds will respond to proposed recreational activities. However, often there is no consideration given to the role of site (resource) quality and the availability of alternative sites in determining how birds will distribute themselves at different spatial scales beyond their immediate behavioural reaction to disturbance (Kershaw 2003, Beale & Monaghan 2004a, 2004b). Furthermore, land managers and responsible authorities often have the difficult task of making decisions about proposed activities that will have consequences over

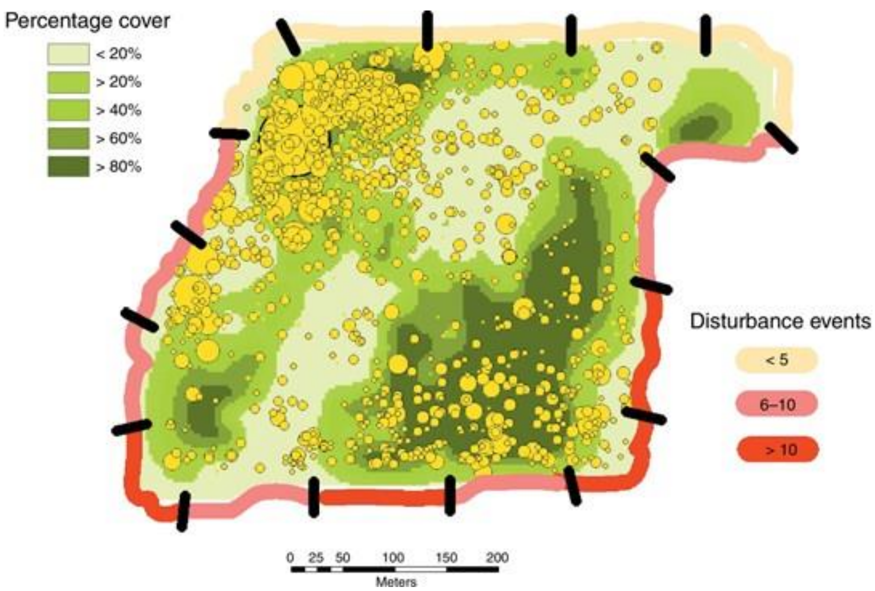

Figure 3. Distribution and relative size of Tufted Duck feeding flocks in January on Lake 31. Flocks (yellow circles) are shown in relation to areas of high and low macrophyte cover and number of disturbance events per hour (walkers and dog-walkers) within recording sectors (separated by black bars).

a range of temporal and spatial scales. For example, the activities may occur only at weekends, or have implications for waterbirds that are only present for 5 months of the year, or disturbance may only occur during a relatively short site development phase. Equally, proposed activities may cause extensive disturbance around the entire periphery of a lake or only a single focal point, on all of the water surface or just a particular zone. At larger spatial extents, waterbirds may ecologically utilize a range of lakes within a wetland system (i.e. for feeding, roosting or moulting), and planning decisions may be required in relation to disturbance on one or many of these sites. The knowledge base supporting planning and decision-making therefore needs to reflect these multi-scale issues (Holling 1992, Ferraro 2004, Beever *et al*. 2006, Hein *et al*. 2006, Houlahan *et al*. 2006). The research programme outlined in this paper will provide information of use at a variety of scales, and that will have utility for developing both within- and between-site zoning of proposed activities (Madsen 1998a). It is hoped that it will also provide an indication of the minimum sampling effort on which planning decisions can be effected. Although there are considerable financial and time costs associated with multi-scale integrated studies, the costs need to be viewed in the context of the total costs of site development or subsequent mitigation measures, and the importance of freshwater sites for a range of wildlife. Lastly, by developing an understanding of the fundamental underlying ecological relationships, it is hoped that the results will be applicable to a range of freshwater situations. This will also be tested as part of the ongoing research programme.

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