The LINNEAN SOCIETY of London BIOLOGICAL Journal of the Linnean Society

Biological Journal of the Linnean Society, 2015, **115**, 494–504. With 6 figures.

Taking the oldest insect recording scheme into the 21st Century

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Received 10 December 2014; revised 3 February 2015; accepted for publication 4 February 2015

The water beetle recording scheme for Britain and Ireland is over 100 years old. For at least half of that time, it has been under the control of Professor Frank Balfour-Browne, who was motivated by a wish to understand the origin of the fauna. The current state of the scheme is discussed in relation to developments from the 1970s onwards, with recognition of the continuing values of an active scheme offered to professional scientists and amateur enthusiasts, as well as a hard copy atlas in the age of electronic data. The next phase of recording will be difficult, requiring a genetic analysis of water beetles that is beyond the reach of most recorders to resolve what Balfour-Browne set out to explore in 1904.

ADDITIONAL KEYWORDS: British Isles – distributions – water beetles.

INTRODUCTION

In celebrating the 50th anniversary of the Biological Records Centre (BRC), it is appropriate to consider the age of recording schemes. It is no surprise to find that the study of water beetles is one of the oldest recording schemes, although it is almost inconceivable that it should represent the oldest insect recording scheme in the world. Irrespective of whether either claim might be true, the BRC anniversary provides a platform for taking stock of how the scheme originated and subsequently progressed, as well as how it might develop in the future.

WATER BEETLES AS A RECORDING GROUP

Aquatic Coleoptera in Britain and Ireland include a diversity of families. The suborder Adephaga may be divided into the aquatic 'Hydradephaga' and the terrestrial Geadephaga, the Carabidae and Cicindelidae. Hydradephaga is not only a convenient term, but also has been recognized as a distinct clade (Hunt *et al*., 2007), with its RNA sequence phylogeny indicating a single land-to-water transition. The adephagous families are the Gyrinidae, Haliplidae, Noteridae, and Paelobiidae, as well as the principal group, the Dytiscidae. Hunt *et al*. (2007) also demonstrated the integrity of the other main suborder, the Polyphaga, within which the land-to-water transition occurred at least eight times, with seven separate aquatic lineages represented in Britain and Ireland by the Dryopoidea, Hydrophiloidea, Hydraenidae, Scirtidae, Donaciinae, Curculioninae, and Nanophyinae. Few of these beetles spend the entirety of their life below water, with most adephagous species coming onto land to pupate, and several groups having aquatic larvae but with adults living on emergent vegetation. Some beetles, mainly weevils, are aquatic at all stages in their life cycle.

An obvious benefit of studying an aquatic group of organisms is that their habitat boundary is well defined and they are thus more amenable to site-listing than most terrestrial animals. However, the potential number of beetle species, from a combined British and Irish list of approximately 400 species, in a water body may depress interest, especially when it becomes clear that the larger species can be as (or more) difficult to identify than the smaller ones (i.e.

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there are traps awaiting would-be recorders for even apparently the most obvious species).

WHAT CONSTITUTES A RECORDING SCHEME?

To substantiate the claim about the age of the water beetle recording scheme, it is desirable to define what is and what is not a scheme. Simply recording one's own findings over time cannot be regarded as a scheme. A scheme must surely involve collating the records of everyone for the chosen group and, preferably, this should involve critical appraisal of those records. As to the group itself, most schemes are based on a taxonomic assemblage or, as in the present case, the fauna of a particular habitat. A scheme could well involve a single species but this would normally be an uneconomical use of time for invertebrate recording. Can a simple compilation of immediately accessible published records constitute a scheme? In that case, almost any insect guide is based on a scheme to provide the basis for comments about distributions. That cannot be right, although it emphasizes the need for the scheme organizer to be actively promoting recording activity rather than relying on records already in the public domain.

The most important requirement of a recording scheme is that it should be motivated by the need to produce something, at least maps, although better an overview of the conservation status of a species or, more dangerously, evidence in support of an hypothesis. A characteristic of a recording scheme associated with mapping is that it must have some recording units, preferably of even size. The earliest units were eighteen 'provinces' in Britain (Watson, 1847), twelve 'districts' in Ireland (Moore & More, 1866), followed by the vice-county systems, then 10-km squares or hectads, and, for the Botanical Society of Britain and Ireland (BSBI), 2-km squares or tetrads.

DEVELOPMENT OF THE FIRST RECORDING SCHEME

Professor Frank Balfour-Browne (1962) took botany and zoology courses at Oxford and Edinburgh Universities. However, he respected his father's wish for him to be called to the Bar, no doubt refining in the process the combative skills for which he became famous. He practised law very little, completed his biology studies at Oxford, and went to work for the Plymouth Marine Laboratory, publishing a work on development of teleost fishes. He was then invited by the Gurney brothers to Norfolk to become director of the Sutton Broad Laboratory (Fig. 1), the first research station in Britain to focus on freshwater. This allowed him to study insect distributions in detail and in a characteristically systematic fashion. His first journal entries in the Broads, from February to August 1903, are largely devoted to Odonata, with a few water beetle records almost as an aside. However, water beetles dominated recording from September 1903 until he ceased fieldwork in 1960. A

Figure 1. Sutton Broad Laboratory in Norfolk. Professor Balfour-Browne was based here from 1903 to 1906, surveying Broadland insects and setting up the water beetle recording scheme. This is now a private house.

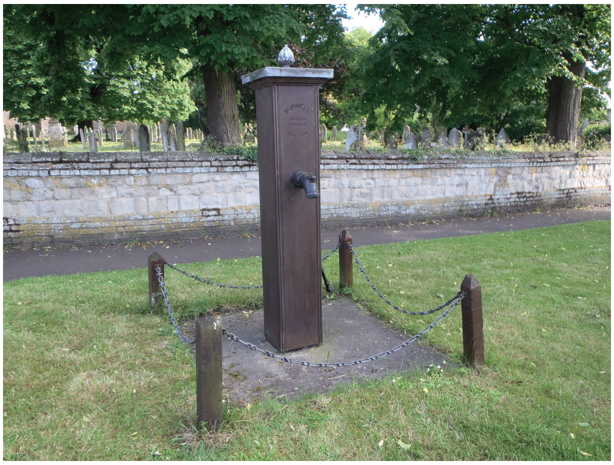

Figure 2. Burwell Village. The plaque commemorates its centenary 1894–1994. It may be the place at which Professor Balfour-Browne first mooted a recording scheme to Dr David Sharp.

critical meeting took place on 20 August 1904 (Balfour-Browne, 1962: 6) at Burwell, Cambridgeshire (Fig. 2):

> I did not make the acquaintance of Dr Sharp until 1904 at the Cambridge meeting of the British Association [for the Advancement of Science – now the British Science Association]. At the time he was Curator of Entomology in the University Museum and I went with him to Burwell Fen where I . . . slaked my thirst at a village pump which I then discovered was 'not for drinking'! . . . It was Sharp who encouraged me when I proposed to make a study of the distribution of the water beetles throughout the Britannic area . . . which naturally led me on to the differences in distribution and how this fitted in with Forbes' theory of successive invasions.

David Sharp (1840–1922) was then the most famous water beetle expert in the world, based on his major publication on the world fauna of Dytiscidae (Sharp, 1882). Fery (2013) lists 800 publications and over 7204 insect names that can be attributed to Sharp, who was regarded as 'the real founder of modern Entomology' (Gardiner, 1928). Another of Balfour-Browne's sources of inspiration was Edward Forbes (1815–1854), who developed a theory that there had been three plant invasions from the Continent, pre-glacial, glacial, and post-glacial, based on their present distribution in Britain and Ireland. Balfour-Browne was determined to evaluate the distributions of water beetles on a similar basis.

Balfour-Browne left Norfolk in October 1906 and took up a lecturing post in Belfast in April 1907. He stayed in Holywood, County Down, presumably near to Robert Lloyd Praeger (1865–1953), who had been born there. Balfour-Browne's initiation into vice-county recording, as opposed to district and county recording, began in Ireland in association with conchologists using the system that Praeger had developed.

Although the precise date on which the discussion took place between Balfour-Browne and Sharp about the desirability of a recording scheme might be open to reinterpretation, there can be no doubt that Balfour-Browne set to very soon after the meeting at Burwell. Amongst the Balfour-Browne Club's memorabilia is his first set of distribution data listed by vice-county and county, with the opening map dated 24 November 1909. The file demonstrates Balfour-Browne's diligence in achieving good coverage of 112 of the original 148 vice-county divisions within 6 years of starting the work. The individual vice-county sheets indicate adoption of Praeger's system with the (then) much debated division of County Kerry (Praeger, 1896). Balfour-Browne (1962) dabbled with grid references but concluded 'It is doubtless an excellent method of recording for military or political purposes and perhaps for trained biologists with a taste for mathematics, but it is quite unsuitable for the amateur who only collects in his spare time'. Balfour-Browne noted a grid reference in his journals only once, NX7765, for a 'small deep quarry hole by road at Mote', Kirkcudbrightshire, on 15 September 1949.

EARLIER RECORDING SCHEMES

Undoubtedly the earliest recording scheme is the *Cybele Britannica* of Hewett Cottrell Watson (1804–1881) on the distribution of plants. This was outlined by Watson (1832) and completed by him (Watson, 1859). Charles Babington (1859), incidentally an early recorder of water beetles, proposed a similar floristic survey in Ireland, completed by Moore & More (1866). The botanists were followed by the conchologists. The Conchological Society was founded in Leeds in 1876. The study of geographical distribution was an interest from the start (Kerney, 1999). A 'Census' scheme was organized by William Dennison Roebuck (1851–1919), based closely on the system employed by the Botanical Exchange Club (the forerunner of BSBI). It was first published as a census by Adams (1902). It is, of course, ridiculous to propose that the rest of the invertebrates were not recorded properly before 1904 but Balfour-Browne's efforts appear to constitute the first detailed arthropod recording scheme in Britain and Ireland, and perhaps even in the world.

One might expect other candidate groups for early recording schemes. Butterfly collecting, for example, is at least 300 years old (Salmon, 2000), although information on butterfly distributions has accumulated rather than being actively collated, that is until John Heath (1922–1987) initiated the Lepidoptera Recording Scheme when working in the BRC in 1967 (Salmon, 2000).

WATER BEETLE RECORDING UNTIL 1960

Balfour-Browne's last journal entry is from October 1960. The three volumes of British Water Beetles (Balfour-Browne, 1940, 1950, 1958), each with vice-county maps of water beetles, might be considered a culmination of the recording scheme. However, he continued to publish until shortly before his death in 1967, and he wrote several lengthy papers drawing on recording scheme data, and principally on the origin of the Irish (Balfour-Browne, 1951) and Scottish faunas (Balfour-Browne, 1953, 1960). It is much to his credit that the early coverage, as converted into 10-km squares, is so good (Fig. 3), and greater (51 000 records) than that associated with his own 28 000 records (Fig. 4).

THE HIATUS AND THE CONTINUATION

Balfour-Browne continued to take an interest in the discovery of water beetles until his death in 1967. However, he ceased identification of material and recording correspondence in 1957. In 1970, Jack Balfour-Browne, Frank's son, wrote to the author saying 'I think it would be a very good thing to get the aquatic Coleoptera added to the European Invertebrate Survey'. He went on to describe how best this might be done. Other commitments prevented a positive response until 1976 when the Balfour-Browne Club was inaugurated followed by the production in 1979 of what was then considered essential, the recording card, and, in the absence then of personal computers, the equally important hand-drawn dot maps.

The benefit of heightening interest in recording activity by a scheme was the recognition of several species new to Britain, *Haliplus varius* Nicolai (Parry, 1982), *Hydroporus elongatulus* Sturm (Foster, 1977), *Hydroporus glabriusculus* Aubé (Sinclair, 1976)

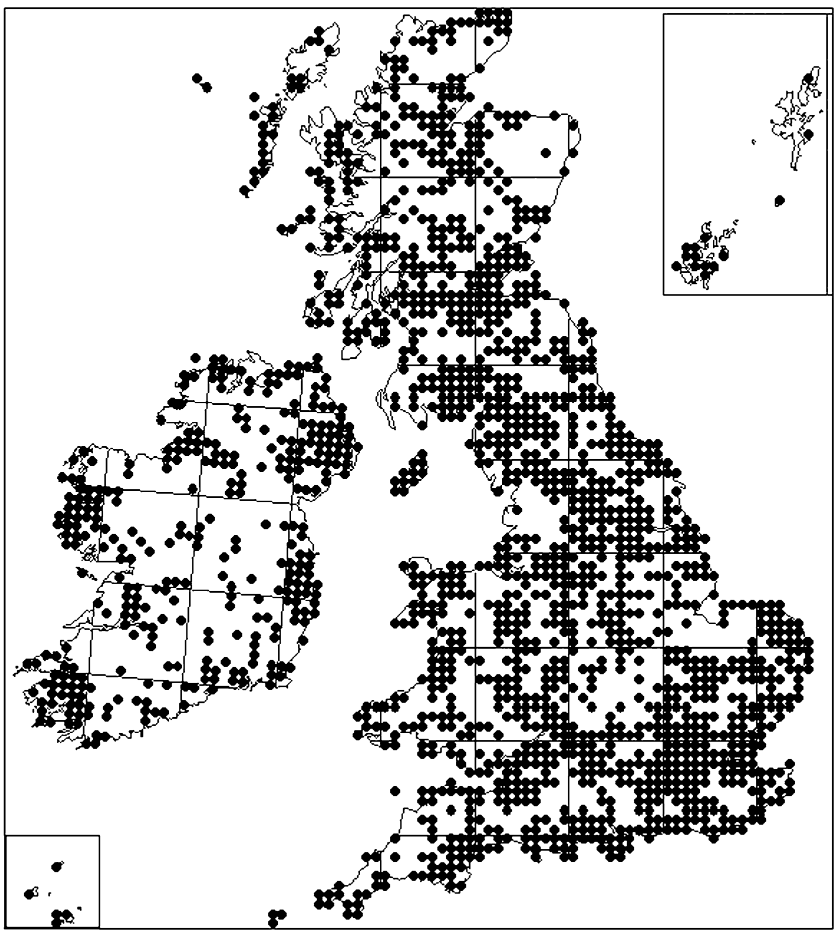

Figure 3. All water beetle records to 1957.

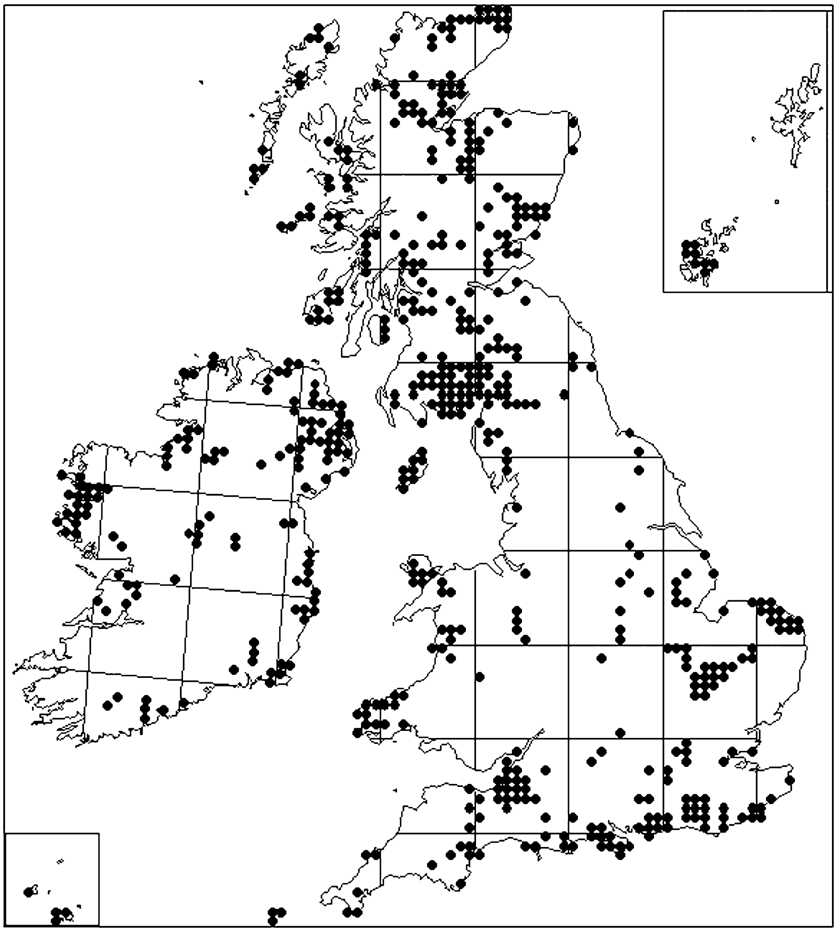

Figure 4. Balfour-Browne's own records.

(Fig. 5), *Hygrotus nigrolineatus* von Steven (Carr, 1984a), *Nebrioporus canaliculatus* (Lacordaire) (Carr, 1999), *Oreodytes alpinus* (Paykull) (Foster & Spirit, 1986), *Enochrus nigritus* Sharp (Foster, 1984), *Limnebius crinifer* Rey (Carr, 1984b), and *Oulimnius major* (Rey) (Parry, 1980).

The elmid *Oulimnius* is a reminder of developments not associated with Balfour-Browne. He corresponded rarely with limnologists, a notable exception being T. T. Macan, and he did not admit riffle beetles (Elmidae) to his recording scheme, even though he occasionally recorded them in the 1900s. Their omission was rectified by David Holland (1972, 1980), who produced the first water beetle 10-km square maps for Britain and Ireland largely based on the routine biological recording of the staff of the water authorities and river purification boards, the predecessors of the environment agencies. Thus, there was a measure of continuity in the 1960s and early 1970s, and it was natural, when the new scheme was developed, to base it on a combination of the recording of enthusiasts and professional limnologists.

FURTHER DEVELOPMENTS

In the early 1980s, those in charge of biological recording schemes learnt that they were recording 'biodiversity', the concept developed by Thomas Lovejoy and E. O. Wilson (Wilson, 1988). Unfortunately, in 1988, they learnt that the Natural Environment Research Council in the UK identified biological recording as one of the areas of lowest priority (NERC Press Notice, 1988). The resulting threat of redundancies within BRC sharpened minds, a good outcome of which was the Coordinating Commission for Biological Recording (CCBR) as inspired by the Berry Report (Berry, 1988). CCBR ultimately resulted in the National Biodiversity Network Gateway.

Despite the uncertainties concerning support for recording schemes, the Joint Nature Conservation Committee promoted the computerization of records, starting with the vice-counties of Cumberland and Westmorland (Foster, 1993). It is worth citing much of the specification of the system used, if only to appreciate subsequent developments in computer systems:

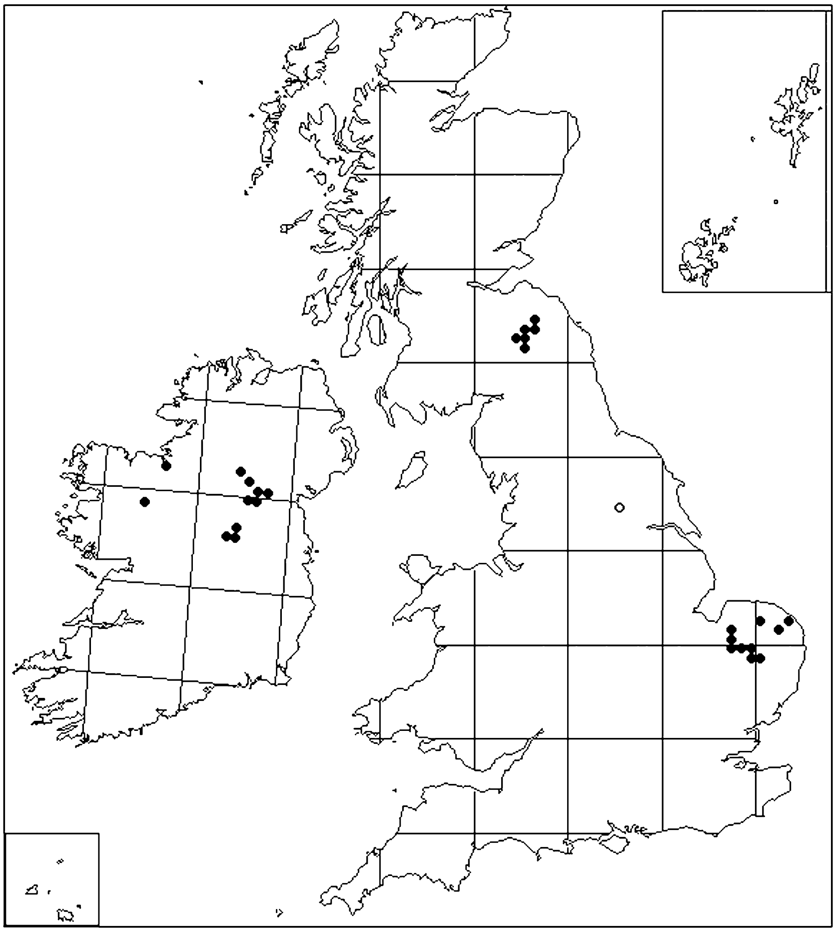

Figure 5. The known distribution of *Hydroporus glabriusculus* Aubé, a species not detected in Professor Balfour-Browne's time, and largely confined to mesotrophic fens in the Borders, the Brecks, and in Central Ireland. There is an old museum specimen from the most famous insect collecting ground in Askham Bog.

'RECORDER (Ball, 1992) and Advanced Revelation Runtime Version 2.0 (Revelation Technologies, 1990) were installed on a Western Systems DX-486 personal computer with 4 Megabytes of RAM and a 170 Megabyte hard disc. The machine was fitted with a tapestreamer to facilitate backing up a large data-set, CPBACKUP being used to compress the data files'. Personal computers have been available ever since the late 1970s, and the subsequent geometric rate of expansion of memory is well known. However, the prospect of a fully computerized recording system independent of a main frame computer was daunting, not necessarily because of technophobia but more as a result of distrust in the reliability of the system. Unreliability was associated with 'glitches' in the original programming, failures as a result of insufficient memory, mistakes made by those inputting the data, and the variability in performance and incompatibilities of a succession of back-up devices. The time- and space-consuming process of transferring all data to recording cards was abandoned in favour of an entirely electronic system in 2000. The problems posed by malware were less important even though computer viruses had been created in the early 1970s in conjunction with the earliest computer networks. Now that most personal computers are 'live', the risks associated with malware are of greater concern: stand-alone personal computers unable to access WIFI may yet prove their worth.

RED LISTS AND TRENDS

The original GB Red Data Book (RDB) statuses (Shirt, 1987) and the original notability statuses (Ball, 1986) were based on published sources and the water beetle recording scheme before it was accessible as an electronic database.

The potential value of computers in facilitating multivariate analysis was appreciated before the recording scheme data were fully computerized. Mark

Hill's programs in FORTRAN (DECORANA: Hill, 1979a; TWINSPAN: Hill, 1979b) could be used to classify water beetle species lists in combination with ranking using RDB statuses and a scoring system based on scores for all species (i.e. not just those considered to be rare or under threat) (Foster & Eyre, 1992).

The classification work in Britain was modelled on an analysis of 289 site lists from Ireland (Foster *et al*., 1992). From 2008 to 2011, coverage of the Republic of Ireland was trebled by an initiative of the National Parks and Wildlife Service and the National Biodiversity Data Centre, Waterford. Coverage of Northern Ireland had been good but was improved in 2007–8 because of the need for common standards monitoring of many Areas of Special Scientific Interest (as designated by the Environment & Heritage Service; now the Northern Ireland Environment Agency). These combined sources of data resulted in a transnational Red List for Ireland (Foster, Nelson & O Connor, 2009) based on criteria developed by the International Union for Conservation of Nature (IUCN, 2003).

The water beetle recording scheme has generated an *ad hoc* collation of observations from many recorders using a variety of methods. It is subject to year-on-year variations in the amount of recording effort and its geographical extent, and rarely includes observations on numbers. Nevertheless, the sheer quantity of data (now in excess of 440 000 records; for an example of coverage of a common species, see Fig. 6) largely eliminates these biases such that trends can be detected. When working for the Joint Nature Conservation Committee, Stuart Ball developed a suite of robust nonparametric tests to identify trends from general biological recording: these are further developed in Ball *et al*. (2011). Three of his tests were used to identify water beetle species with declining ranges as part of the analysis for the UK Red List (Foster, 2010):

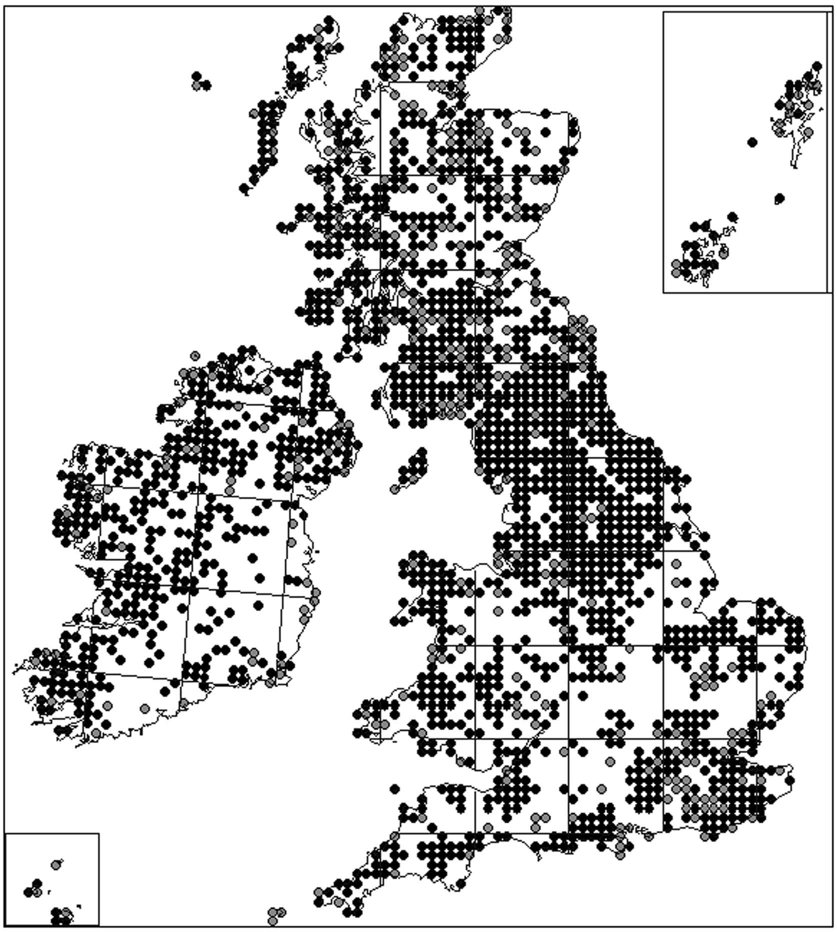

Figure 6. The known distribution of one of the commonest diving beetles, *Hydroporus pubescens* (Gyllenhal), demonstrating that gaps in recording still exist, although, in most cases, these are in areas where standing water is scarce. The paler 10-km symbols are for records before 1980.

1. The percentage change in hectads recorded before 1990 and after 1989 (50% of all records are post 1989), a 25% reduction being used as a threshold for species of conservation concern;
2. Significant value ($P < 0.05$) for Spearman's rank correlation coefficient for the correlation between year order and the proportion for the species of all records received in each year;
3. Significant value ($P < 0.05$) for Spearman's rank correlation coefficient for the correlation between year order and the proportion of hectads recorded for the species in each year.

Very few species showed a significant decline using all the tests available, even though there were sufficient data, year-on-year, to detect trends for approximately half of the fauna, with 200 species having been recorded more than 100 times within the 27 years to 2008. They include: six Gyrinidae; fifteen Haliplidae; the sole representative of the Paelobiidae, *Hygrobia hermanni* (Fabricius); both British members of the Noteridae; 84 Dytiscidae; thirteen Helophoridae; three Hydrochidae; 35 Hydrophilidae; fourteen Hydraenidae; five Elmidae; two Dryopidae; one Heteroceridae, *Heterocerus fenestratus* (Thunberg); eleven Scirtidae; and eight leaf beetles and weevils. Only seven species of water beetle in the database showed significant decline using all three statistics. Five of these were running water species: *Brychius elevatus* (Panzer), *Oreodytes davisii* (Curtis), *Oreodytes sanmarkii* (Sahlberg), *Oreodytes septentrionalis* (Gyllenhal), and *Stictotarsus duodecimpustulatus* (Fabricius); all were free-swimming species of running water margins as opposed to the common riffle beetles that normally occupy the main river channel and none showed any significant decline. This was taken to indicate the importance of loss of riparian structure as opposed to pollution. *Oreodytes davisii* was selected for the Near Threatened status as the least common of this suite of running water species. The remaining two species were the hydraenid *Limnebius papposus* Mulsant and the diving beetle *Porhydrus lineatus* (Fabricius). *Limnebius papposus* is associated with lowland peat and it was assigned a threat category with some confidence. On the other hand, *P. lineatus* is a lowland species of rich fen in ponds and in drainage ditches on grazing fen. Although it appears to have undergone a 40% decline subsequent to 1980, *P. lineatus* continues to occupy much of its known range, indicating the need for a fourth test based on reduction in known range. *P. lineatus* was not assigned a threat or near threatened status.

Many water beetle species are too scarce to generate sufficient data from which to quantify trends statistically, and most of these scarce species have gained Red List status on the basis a restricted number of sites occupied and consequent small extent of occurrence or area of occupancy as defined in IUCN (2003). However, Philip Shaw (2005) was able to use data from some of these scarce species in a sample of 4019 animal and plant species employed to estimate extinction rates in Scotland. He found an insect extinction rate of 2.5% of all species in 1950–1999 compared to an overall rate of 1.2–1.8%.

FUTURE DEVELOPMENTS

The atlas in preparation must surely mark the end of the second phase of recording of water beetles in Britain and Ireland. Some biological recorders might nowadays regard a hard copy atlas as a retrograde step, with all of the effort being preferably directed to an up-to-the-minute, online facility. In practice, the preparation of some basic text to accompany a set of maps has proved highly beneficial. Recorders are alerted to submit record backlogs. The exercise provides a further check on unusual records and on misplaced grid references. The chain of enquiry based on comparison of the new maps with what has been published often elicits additional information. Much of the database was created before the web achieved its present prominence, and there was an accumulation of records for which sites could not be located except by extensive archival research and guesswork. Search engines have greatly improved our ability to locate previously obscure sites, and online access to journals has greatly improved library searches. Another modern development has been high-resolution digital photography. Photographs are used for barely 1% of the 12 000–15 000 records currently being acquired, although their use is increasing annually.

One can envisage a dividing of the ways in future recording efforts, with a populist 'citizen science' approach leading recorders in one direction and a more fundamental appreciation of the status of species as identified by genetic analysis leading professional entomologists in an altogether different direction. The fragile status of our understanding of what constitutes many species is hinted at in the handbook concerning the Hydrophiloidea (Foster, Bilton & Friday, 2014) and even the Hydradephaga are seen to have potential for recognition of new species and races that might begin to explain the origins of the British and Irish faunas (Ribera, Vogler & Balke, 2008; Bergsten *et al.*, 2012; Bergsten, Nilsson & Ronquist, 2013).

This divergence problem is not really new. Robert Angus has pioneered recognition of species and races by the use of their karyotypes, requiring access to living material and a specialist laboratory. There do not appear to be any taxonomic problems in Britain and Ireland on a par with distinguishing *Helophorus paraminutus* Angus from *Helophorus minutus* Fab. in Central Europe (Angus, 1986), the nearest being within *Anacaena lutescens* (Stephens) where a chromosomal abnormality distinguishes a parthenogenetic race (Shaarawi & Angus, 1991). Where they occur together, the bisexual and parthenogenetic populations can only be distinguished by chromosome analysis, although the more northern extent of the parthenogenetic form can be recognized by the northern individuals being solely female. An otherwise similar problem, the reluctance of many amateur coleopterists to dissect the male genitalia, can be resolved by access to voucher material.

It is difficult to see how the populist and the professional approaches can continue to be aligned. For example, the larger water beetles have been treated separately (Sutton, 2008) as a group attracting amateur interest, although they can prove almost as difficult to identify as many smaller ones, with the larvae of some *Dytiscus* species being indistinguishable morphologically. Serjeant & Beebee (2013) demonstrated that the latter problem might be resolved by use of a DNA probe accessible to enthusiasts at no great expense. Unfortunately, with the completion of the project, that probe no longer exists. One can only hope that those adopting the molecular approach will continue to recognize their need of the amateur's knowledge to lead them to their quarry, and that the quarry, as defined by its DNA or by proteomics (Hidalgo-Galiana *et al*., 2014), yields answers to the questions that motivated Balfour-Browne in 1904.

Validation of data has always been an issue. This problem could be exacerbated by the improved methods of data capture claimed for modern systems (August *et al*., 2015) in that data can be captured that are best ignored. The computer will not resolve this problem because there is insufficient expert guidance to go round to eliminate poor quality information. In any case, expert opinion will become more divided because of what computer-guided systems can really achieve (i.e. to resolve DNA sequences to identify phenomena such as coexisting haplotype clusters): the problem is then that experts will disagree on the extent to which haplotypes can be considered as cryptic species in the absence of morphological differences; for example, see the treatments of two running water species, *Agabus biguttatus* (Olivier) and *Agabus guttatus* (Paykull), by Bergsten *et al*. (2012). The real division of the ways may be between those who know and those who think they know. But which is which?

ACKNOWLEDGEMENTS

The present account has benefited from various discussions, particularly with Paul Harding OBE. Margaret Palmer, when working for the Joint Nature Conservation Committee, should be singled out for promoting the original computerization of the water beetle data. Alan Morton is thanked for producing a simple and elegant mapping system in DMap. Staff of the Biological Records Centre, Wallingford, in particular Helen Roy, and staff of the National Biodiversity Data Centre, Waterford, are thanked for their continuing support. The present paper was developed from a talk prepared for the meeting to celebrate the 50th Anniversary of the Biological Records Centre.

REFERENCES

Adams CE. 1902. The census of the British land and freshwater Mollusca. *Journal of Conchology* **10:** 217–237.

Angus RB. 1986. Revision of the Palaearctic species of the *Helophorus minutus* group (Coleoptera: Hydrophilidae), with chromosome analysis and hybridization experiments. *Systematic Entomology* **11:** 133–163.

August T, Harvey M, Lightfoot P, Kilbey D, Papadopoulos T, Jepson P. 2015. Emerging technologies for biological recording. *Biological Journal of the Linnean Society* **115:** 731–749.

Babington CC. 1859. Hints towards a Cybele Hibernica. *Proceedings of the Dublin University Zoological & Botanical Association* **1:** 246–250.

Balfour-Browne F. 1906. A study of the aquatic Coleoptera and their surroundings in the Norfolk Broads district. *Transactions of the Norfolk and Norwich Naturalists' Society* **8:** 290–307.

Balfour-Browne F. 1940. *British water beetles*, Vol. 1. London: Ray Society.

Balfour-Browne F. 1950. *British water beetles*, Vol. 2. London: Ray Society.

Balfour-Browne F. 1951. The aquatic Coleoptera of Ireland. with some remarks on the causes of their distribution. *Entomologist's Gazette* **2:** 1–52.

Balfour-Browne F. 1953. The aquatic Coleoptera of the Western Scottish Islands with a discussion on their sources of origin and means of arrival. *Entomologist's Gazette* **4:** 79–127.

Balfour-Browne F. 1958. *British water beetles*, Vol. 3. London: Ray Society.

Balfour-Browne F. 1960. The aquatic Coleoptera of Scotland and their routes of arrival. *Entomologist's Gazette* **11:** 69–106.

Balfour-Browne F. 1962. *Water beetles and other things. Half a century's work*. Dumfries: Blacklock Farries & Sons Ltd.

Ball SG. 1986. *Terrestrial and freshwater invertebrates with Red Data Book, notable or habitat indicator status*. Invertebrate Site Register 66. Peterborough: Nature Conservancy Council.

Ball SG. 1992. *Recorder*, Version 3.1. Peterborough: English Nature.

Ball SG, Morris R, Rotheray G, Watt K. 2011. *Atlas of the hoverflies of Great Britain (Diptera, Syrphidae)*. Wallingford: Biological Records Centre.

Bergsten J, Bilton DT, Fujisawa T, Elliott M, Monaghan MT, Balke M, Hendrich L, Geijer J, Herrmann J, Foster GN, Ribera I, Nilsson AN, Barraclough TG, Vogler AP. 2012. The effect of geographical scale of sampling on DNA barcoding. *Systematic Biology* **61:** 851–869.

Bergsten J, Nilsson AN, Ronquist F. 2013. Bayesian tests of typology hypotheses with an example from diving beetles. *Systematic Biology* **62:** 660–673.

Berry RJ. 1988. *Biological survey: need and network*. London: Linnean Society/PNL Press, [48 pp].

Carr R. 1984a. A *Coelambus* species new to Britain (Coleoptera: Dytiscidae). *Entomologist's Gazette* **35:** 181–184.

Carr R. 1984b. *Limnebius crinifer* Rey new to Britain, with a revised key to the British *Limnebius* species (Coleoptera: Hydraenidae). *Entomologist's Gazette* **35:** 99–102.

Carr R. 1999. *Nebrioporus canaliculatus* (Lacordaire in Boisduval & Lacordaire) new to Britain. *Latissimus* **11:** 36.

Fery H. 2013. David Sharp (1840–1922). A bibliography and a catalogue of his insect names. *Skörnöpparn, Umeå Supplement* **4:** 1–114.

Foster GN. 1977. *Hydroporus elongatulus* Sturm (Col., Dytiscidae) new to Britain. *Entomologist's Monthly Magazine* **112:** 13–18.

Foster GN. 1984. Notes on *Enochrus* subgenus *Methydrus* Rey (Coleoptera: Hydrophilidae), including a species new to Britain. *Entomologist's Gazette* **35:** 25–29.

Foster GN. 1993. An aquatic Coleoptera database for North West England. *Joint Nature Conservation Committee Report* 176. Peterborough: Joint Nature Conservation Committee.

Foster GN. 2010. *A review of the scarce and threatened Coleoptera of Great Britain. Part 3: water beetles*. Species Status No. 1. Peterborough: Joint Nature Conservation Committee.

Foster GN, Bilton DT, Friday LE. 2014. Keys to the adults of the water beetles of Britain and Ireland (Part 2). In: *Handbooks for the Identification of British Insects*. Volume 4, Part 5b. St Albans: Royal Entomological Society.

Foster GN, Eyre MD. 1992. Classification and ranking of water beetle communities. *UK Nature Conservation No. 1*. Peterborough: Joint Nature Conservation Committee.

Foster GN, Nelson BH, Bilton DT, Lott DA, Merritt R, Weyl RS, Eyre MD. 1992. A classification and evaluation of Irish water beetle assemblages. *Aquatic Conservation: Marine & Freshwater Ecosystems* **2:** 185–208.

Foster GN, Nelson BH, O Connor A. 2009. *Ireland Red List No. 1. Water beetles*. Dublin: National Parks & Wildlife, Department of Environment, Heritage & Local Government.

Foster GN, Spirit M. 1986. *Oreodytes alpinus* new to Britain. *Balfour-Browne Club Newsletter* **36:** 1–2.

Gardiner JS. 1928. 26. Wicken Fen. In: Gardiner JS, ed. *The natural history of Wicken Fen*. Cambridge: Bowes & Bowes, 371–383.

Hidalgo-Galiana A, Monge M, Biron DG, Canals F, Ribera I, Cieslak A. 2014. Reproducibility and consistency of proteomic experiments on natural populations of a non-model aquatic insect. *PLoS ONE* **9:** 1–11.

Hill MO. 1979a. *DECORANA – a FORTRAN program for detrended correspondence analysis and reciprocal averaging*. New York, NY: Cornell University.

Hill MO. 1979b. *TWINSPAN – a FORTRAN program for arranging multivariate data in an ordered two-way table by classification of individuals and attributes*. New York, NY: Cornell University.

Holland DG. 1972. *A key to the larvae, pupae and adults of the British species of Elminthidae*. Freshwater Biological Association Scientific Publication **26**. Ambleside: Freshwater Biological Association.

Holland DG. 1980. Distribution of Elmidae/Elminthidae. *Balfour-Browne Club Newsletter* **16:** 1–12.

Hunt T, Bergsten J, Levkanicova Z, Papadopulou A, St John O, Wild R, Hammond PM, Ahrens D, Balke M, Caterono MS, Gómez-Zurita J, Ribera I, Barraclough TG, Bocakova M, Bocak L, Vogler AP. 2007. A comprehensive phylogeny of beetles reveals the evolutionary origins of a superradiation. *Science* **318:** 1913–1916.

IUCN. 2003. *Guidelines for application of IUCN Red List criteria at regional levels*, Version 3.0. Gland: IUCN.

Kerney M, ed. 1999. *Atlas of the land and freshwater molluscs of Britain and Ireland*. Colchester: Harley Books.

Moore D, More AG. 1866. Contributions to a *Cybele Hibernica, being outlines of the geographical distribution of plants in Ireland*. Dublin: Hodges, Smith & Co.

NERC. 1988. Manpower cuts at NERC. NERC Press Notice 21/88.

Parry JA. 1980. *Oulimnius major* (Rey) (= *O. falcifer* Berthélemy) (Col.: Elmidae) new to Britain. *Entomologist's Record & Journal of Variation* **92:** 248.

Parry JA. 1982. The new broom. *Balfour-Browne Club Newsletter* **23:** 1–2.

Praeger RW. 1896. On the botanical subdivision of Ireland. *The Irish Naturalist* **5:** 29–38.

Revelation Technologies. 1990. *Advanced revelation runtime,* Version 2.0. Westwood, NJ: Revelation Technologies, Inc.

Ribera I, Vogler AP, Balke M. 2008. Phylogeny and diversification of diving beetles (Coleoptera: Dytiscidae). *Cladistics* **24:** 563–590.

Salmon MA. 2000. *The Aurelian legacy. British butterflies and their collectors*. Colchester: Harley Books.

Serjeant AP, Beebee TJC. 2013. Identification of *Dytiscus* larvae by cytochrome oxidase I (COI) partial sequencing. *Journal of Insect Conservation* **17:** 1191–1196.

Shaarawi FA, Angus RB. 1991. A chromosomal investigation of five European species of *Anacaena* Thomson (Coleoptera: Hydrophilidae). *Entomologica Scandinavica* **21:** 415–426.

Sharp D. 1882. On aquatic carnivorous Coleoptera or

Dytiscidæ. *Scientific Transactions of the Royal Dublin Society* **2:** 179–1003.

Shaw P. 2005. Estimating local extinction rates over successive time-frames. *Biological Conservation* **121:** 281–287.

Shirt DB, ed. 1987. *British Red Data Books: 2. Insects*. Peterborough: Nature Conservancy Council.

Sinclair M. 1976. *Hydroporus glabriusculus* Aubé (Col., Dytiscidae) new to the British Isles. *Entomologist's Monthly Magazine* **111:** 117–121.

Sutton P. 2008. *The larger water beetles of the British Isles*. Orpington: Amateur Entomologists.

Watson HC. 1832. *Outlines of the geographical distribution of British plants: belonging to the division of vasculares or cotyledones*. Printed for private distribution, Edinburgh.

Watson HC. 1847. 1859. *Cybele Britannica; or British plants and their geographical relations*. London: Longman.

Wilson EO. 1988. *Biodiversity*. Washington: The National Academies Press.