October 2011

Biodiversity Audit and Tolerance Sensitivity Mapping for the Broads

Broads Authority
The Broads - a member of the National Park family

The Broads Biodiversity Audit is a Broads Authority initiative, undertaken by the University of East Anglia, supported by Natural England and working with the conservation organisations in the Broads area.

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Contents

Appendix B:

Glossary

Abbreviations for designations:
RDB – National Red Lists, Red Data Book
GRDB – Global IUCN list, Global Red Data Book
CR: Critically Endangered
DD: Data Deficient
EN: Endangered
EW: Extinct in the Wild
EX: Extinct
INDE: Indeterminate
INSU: Insufficiently known
LR: Lower risk - conservation dependent
NT: Near Threatened
R: Rare
RE: Regionally Extinct
VU: Vulnerable
N – Nationally Rare/Scarce, Notable
N:A – Nationally Rare/Scarce, Notable:A
N:B – Nationally Rare/Scarce, Notable:B
S:NS – Nationally Rare/Scarce, Status: Near Scarce
S:NR – Nationally Rare/Scarce, Status: Near Rare
M:NS – Nationally Rare/Scarce, Marine: Near Scarce
BAP – Biodiversity Action Plan UK priority list
B:R – Birds of Conservation Concern, Bird: Red
B:A – Birds of Conservation Concern, Bird: Amber
SPA – EU Special Protection Area
SAC – EU Special Area of Conservation
SSSI – Site of Special Scientific Interest

Definitions:
Extirpated – local extinction from an area or region, but not extinct nationally
Extinct – in the context of this report, extinct refers to a species which no longer occurs within the UK (this may include species that are globally extinct)
Phytophagous – an organism feeding on plants
Axiophytes are 'worthy plants' - the 40% or so of species that arouse interest from botanists when they are seen. They are indicators of habitat that is considered important for conservation, such as ancient woodlands, clear water and species-rich meadows (http://www.bsbi.org.uk/axiophytes.html)

Organisational Acronyms:
BA – Broad Authority
EA – Environment Agency
NBIS – Norfolk Biodiversity Information Service
NBN – National Biodiversity Network
NE – Natural England
NWT – Norfolk Wildlife Trust
RSPB – Royal Society for the Protection of Birds
SBRC – Suffolk Biological Records Centre
UEA – University of East Anglia

Taxonomy:
Actinopterygii – Bony fish
Agnatha – Jawless fish
Araneae – Spiders
Bryozoa – aquatic filter feeding invertebrates
Coleoptera – Beetles
Dermaptera – Earwigs
Dictyoptera – Cockroach
Diptera – True fly
Ephemeroptera – Mayflies
Hemiptera – True Bugs
Hymenoptera – Bees, Wasps and Ants
Lepidoptera – Butterflies and moths
Odonata – Dragonflies and Damselflies
Orthoptera – Grasshoppers and Crickets
Plecoptera – Stonefly
Trichoptera – Caddis fly


Norfolk Hawker
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Executive Summary

Biodiversity underpins ecosystem functions that provide valuable services, such as carbon sequestration, water quality and flood defence. Furthermore, biodiversity is itself an important service of ecosystems, contributing to human well-being and having cultural value and immeasurable intrinsic value. The Natural Environment White Paper (NEWP, 2011), the Lawton Report (2010) and the National Ecosystem Assessment (UNEP-WCMC, 2011) highlight the value of such services and aim to increase the ecological coherence and resilience of the UK protected site network in order to increase the resilience of biodiversity and ecosystem functions to anthropogenic climate change.

National Park Authorities (NPAs) actively influence the management of 10 % of Britain's land area and make a significant national and regional contribution to mitigating and adapting to climate change through flood control, water conservation, carbon conservation, biodiversity conservation and promoting sustainable farming. All of these ecosystem services and land-uses are cogent within the Broads Executive Area.

The current study, commissioned by the Broads Authority with the support of Natural England, aimed to:

- Examine and quantify the biodiversity importance and uniqueness of differing habitats and landscape elements within the Broads Authority Biodiversity Action Plan area (covering 1,122 1-km squares), to provide an evidence-base to underpin conservation priorities and strategic adaptive planning.
- Analyse and classify the sensitivity of multiple species to saline incursion, flooding and drying, to define groups of species with similar tolerances (tolerance assemblages), and map the distribution of these assemblages to provide an evidence layer that can then be linked to saline incursion maps and climate change scenarios.
- These can then be used to support adaptive management, as proposed by the Phase 2 Strategic risk and adaptation assessment of the Broads Authority Proposal for Salinity, Hydrology and Climate Change Risk Assessment in the Broadland Fens (August 2010).

Available species records were collated following methodologies developed during the Breckland Biodiversity Audit (Dolman et al. 2010), capturing and combining significant systematic surveys, together with a large number of previously un-collated records. This provided a collated electronic database of 1,507,648 biological records spanning 1670-2011, of which 174,931 post-1988 records were used to map contemporary priority biodiversity distributions.

This showed that 11,067 taxa (species aggregates, species and designated sub-species or varieties) have been recorded in The Broads, of which 1,519 are priorities for conservation (being BAP priority species, RDB, Nationally rare or scarce, Red or Amber listed bird species or Broads Specialities), including 403 beetle species, 251 true flies and 179 moth species. These include 26% of all UK BAP species, 13% of all UK RDB and 17% of all nationally notable or scarce species. The Broads also provides habitat for 85% of the UK Bird: Red species and 94% of the Bird: Amber. Sixty-six species were identified as Broads Specialities, of which 31 are entirely or largely restricted to the Broads within the UK (≥ 80% of UK range, assessed as 10-km squares, or population size) and a further 35 have a primary stronghold in the region (≥ 50% of UK range or population size). This exceeded previous understanding of the unique contribution of The Broads. Together, these confirmed and, for the first time quantified, the importance of the Broads to UK biodiversity.

Systematic analysis of the habitat associations of priority species confirmed the outstanding importance of peat fens to biodiversity within the Broads. However, it also showed the importance of other habitats. In order of relative importance these are:

> Fen, Wet Grassland, Dry Grassland, Wood Pasture, Woodland, Small Standing Waterbodies, Heathland, Littoral and Lake margins, Coastal, Sand Dune, Brownfield, Reedbed, Arable.

Although fewer species were found to be associated with ditches and dykes compared to other habitats, wet grassland habitats and grazing marsh landscapes, which are characterised by ditches, supported large numbers of priority species.

Broads Specialities were concentrated in fen habitats, particularly those in the Ant and Bure valleys. Other habitats of importance to Broads Specialities included (in rank order):

> Wet Grassland, Small Standing Waterbodies, Reedbed and Reed Swamp, Ditches and Dykes.

No recent (≤1988) record was found for 423 (28%) of the 1,519 priority species. Of these, at least 67 were reported to be regionally or nationally extinct. The status of the remaining 356 species is unknown, and targeted surveying is recommended. Species with no recent record were more often associated with dry or damp ecotonal habitats than extant species. Many species reported to be regionally or nationally extinct were primarily associated with dry grassland, brown field or arable habitats. Thus terrestrial (non-wetland) biodiversity has been particularly depleted as agriculture has intensified. Extirpated (locally extinct) species included 13 species associated with fen, 11 species with wet grassland and 11 species with littoral and lake margins, including many reed beetles (*Donacia* sp.) with a particular concentration of records of extirpated wetland species noted in the valley of the River Ant.

Methodologies were developed to classify the tolerance of large numbers of priority species to salinity, flooding and drying. Of the 1,096 priority species for which recent records were obtained, 1053 (96%) were successfully coded for hydrological and salinity tolerance. Sixty-three percent of priority species, including 79% of Broads Speciality invertebrates, require fully freshwater conditions and are considered to be unlikely to tolerate brackish influence. Thirteen percent of priority species were classified as tolerating mild to moderately brackish or saline conditions, and these were dominated by vertebrates.

Mapping of the saline tolerances of species confirmed the high importance of the Ant, Bure Marshes and Mid-Yare, which support the highest richness of priority species that are dependent on freshwater and vulnerable to saline influence. Other notable hotspots include the Thurne (Hickling area), Burgh Common and Muck Fleet, and to a lesser extent the lower Waveney and wetlands in the Oulton Broad area. The same range of areas also support high richness of species tolerant of mild saline influence, but the relative proportion of this group within records is lower in the key fens of the Ant, Bure and Mid-Yare. Saline tolerant species are particularly notable in the grazing marsh complexes of the lower reaches of the Yare and Bure. The Thurne catchment is notable for the heterogeneity of its assemblage, with freshwater dependent, mildly brackish and saline tolerant elements. The maps will support strategic adaptation and mitigation measures.

Comparisons of river conductivity and chloride concentrations indicated that, in the Broads relationships between conductivity (µS/cm) and salinity are complex, and may be site-specific. In moderately to strongly saline influenced areas (e.g. at Brograve Pump) there was a strong relationships between chloride and conductivity. However, in the upper reaches of some rivers with little saline influence (e.g. at Honing Lock), other ions make significant contributions to the conductivity and there are weak relationships between chloride concentration and conductivity; in these circumstances conductivity is a poorer measure of salinity. Conductivity is a fast and cost-effective method of measuring relative salinity and is likely to be an appropriate measure to detect major saline events, but it should not be used to monitor for small changes in salinity.

Fifty-two percent of the priority species in the Broads are associated with dry or damp conditions (i.e. generally have a very high vulnerability to increased water levels and a high tolerance to drought). However, these include only three Broads Speciality species. Most (59%) Broads Specialities are associated with wet habitats, with a high vulnerability to droughting and some vulnerability to flooding. Fully aquatic species only comprise 10% priority species but 25% of Broads Specialities.

Species were classified according to the upper limit of their tolerance to salinity. This followed a consistent and systematic methodology, making use of a number of sources of evidence for tolerance, primarily from known distributions of species. However, we acknowledge some species may have been attributed to an incorrect category, but believe that most species were correctly coded and we were able to independently validate the classification of a sub-set of invertebrates (testing 75 species) as a measure of accuracy. More importantly, although we are confident that species of a given salinity category will not tolerate consistently higher (or in some cases lower) salinities, an important area of uncertainly arises from the extent to which species could tolerate *brief* episodes of differing salinity. Species tolerance of such episodes will depend on the frequency and intensity of saline incursions and the duration and persistence of the raised salinity, which in turn will be affected by hydrological characteristics of individual sites and the timing of the episode in relation to vulnerable or resistant life history stages. The information currently available is insufficient to assess this. The methodology used in this study, therefore, provides an understanding of the distribution of vulnerable priority species, predicts that persistent or repeated saline incursion would deplete intolerant assemblages, but cannot quantify the proportion of species depleted by infrequent and ephemeral incursions. In contrast, the tolerances of species to hydrological changes were inferred from best available evidence for aspects of species life history, ecology and natural history. Similarly to saline tolerances, the effects of rapid hydrological change will depend on the season and corresponding life cycle stage, and the water quality, duration and persistence of the conditions. We were unable to locate information for known species responses to episodes of drying or flooding. As a result, the confidence that can be placed in these hydrological tolerances is reduced. We consider the classification provisional and would benefit from further development through input from species experts.

Summary of Recommendations

Recommendations are outlined in full on page 65. A summary of the key recommendations have been agreed by the steering group as worthy of further exploration.

A1 & A2: Develop strategic priorities to strengthen biological recording coverage in The Broads and increase understanding of status of priority species with no recent observations (post 1988) guided by a steering group led by the Broads Authority

B: Maintain the existing biodiversity databases for the future led by NBIS and SRC

C: Communicate and increase recognition for the biodiversity importance of The Broads

D & E: Improve site networks and strategic planning for non-wetland habitats within The Broads to address the documented loss of biodiversity in areas around the Broads

F: Increase understanding and monitoring of appropriate indicators of biodiversity

G: Assess the utility of axiophytes as indicators of habitat quality and environmental change

H: Secure long-term surveillance and monitoring of biodiversity particularly that associated with environmental conditions

I: Explore site specific temporal changes in species compositions, particularly in relation to climate change

J: Develop the priority species vulnerability and risk assessment alongside potential mitigation and adaption activities

K: Use the Biodiversity Audit information to assess future landscape change scenarios and the implications for biodiversity and ecosystem services

Introduction and Background

The Natural Environment White Paper (NEWP, 2011) addressed recommendations from the Lawton Report *Making Space for Nature* (2010) to increase the ecological coherence and resilience of the UK protected site network, particularly in the face of climate change. NEWP adds to the England Biodiversity Strategy (*Working With The Grain Of Nature*, 2002, revised 2011) to meet the Biodiversity 2020 targets. NEWP is instrumental to delivering the UK commitment to the 2010 Nagoya agreements and the Convention on Biological Diversity (CDB) and other national and international biodiversity commitments, such as the European Landscape Convention. NEWP outlined guidelines and commitments to facilitate greater local action to protect, improve and support recovery of the natural environment. In particular, this is to be achieved by supporting ecosystem function, restoring natural networks and growing a green economy to sustain natural capital and ecosystem services that underpin economic growth.

Biodiversity underpins ecosystem functions that provide services (supporting, regulating, provisioning, e.g. carbon sequestration, water quality, flood defence), but biodiversity is itself also an important service of ecosystems, providing human well being, cultural value and immeasurable intrinsic value. A key aim of the NEWP (2011), the Lawton Report, and the National Ecosystem Assessment (UNEP-WCMC, 2011) is to increase the resilience of biodiversity and ecosystem functions to current and future anthropogenic climate change. The UK Climate Change Risk Assessment, to be finalised by Defra in early 2012, will prioritise adaptation policy and gather evidence for biodiversity and ecosystem services. It will likely identify a need for data to assess the risk from climate change and a metric for 'adaptedness' of biodiversity.

Climate changes modelled by the UK Climate Predictions (UKCP09), based on various scenarios of emissions of greenhouse gases (Murphy et al. 2009), predict that by the 2050s and under medium emissions scenarios[1], the East of England is predicted to experience:

Hotter summers – with **s**ummer mean temperatures predicted to increase by 2.5 °C with an increase of 3.4°C in summer mean daily maximum temperature
Drier summers – with mean summer precipitation predicted to decrease by 17%
Milder winters – with winter mean temperatures predicted to increase by 2.2 °C
Wetter winters – with winter mean precipitation predicted to rise by 14%
Sea level rise – with relative sea levels in Great Yarmouth predicted to be 24.3 cm higher

[1] values given are central estimates; more details of probabilities and climate changes are available at http://ukclimateprojections.defra.gov.uk

Climate impacts will manifest through changes in phenology, changes in species range as tolerances/thresholds are exceeded, invasion and alteration in the composition of species assemblages, changes in competition and predation, and changes in environmental conditions that include drying, wetting, changes in flooding regimes, milder wetter winters, and loss of habitat area, particularly through sea level rise and coastal retreat. In the Broads, hotter drier summers may cause localised drying of fen and wet grassland, but with local effects influenced by recharge from the underlying aquifer that will in turn be influenced by levels of winter rainfall (projected to increase). Wetter winters, and an increase in high rainfall events, may increase the risk of river over-topping. Potential increases in frequency and intensity of extreme weather events, including strong winds and storm surges in the North Sea, may further increase flood risk. Furthermore, climate change will have a significant effect on farmers and land managers and on the land that they manage (e.g. CSERGE SEER[2]), with additional consequences for biodiversity and ecosystem services.

The majority of the potential issues arising from climate changes that were identified by the draft Broads Climate Change Adaptation Plan require water level management (Broads Authority 2011). Other mitigation measures may include improving resilience (for example through improved connectivity and networks, and through increased landscape site- and patch-scale heterogeneity), translocation of species, knowledge transfer and communication of adaptation plans, and accommodating changes through accepting species extinction and turn over.

Catchment management to mitigate the effects of agriculture and other land-uses on water quality, and to increase resilience to climate impacts, has been implemented in the UK by a wide range of initiatives. These include the Association of Rivers Trusts (ART), The Rural Economy and Land Use (RELU) programme *Catchment Management for the Protection of Water Resources: A Template*[3], by trials undertaken in the Environment Agency Pilot Catchments[4] to encourage partnership and widening participation to improve water quality in relation to the Water Framework Directive, and by the Defra-LWEC (Living with Environmental Change) Demonstration Test Catchments (DTCs)[5], including the Wensum DTC[6], with trials designed to achieve farm profitability and maintain food security while improving water and ecosystem quality.

The Broads – a member of the National Park Family

National Park Authorities (NPAs) actively influence the management of 10 % of Britain's land area and are well positioned to make a significant national and regional contribution to mitigating and adapting to climate change through flood control, water conservation, carbon sequestration, biodiversity conservation and sustainable farming. All of these ecosystem services and land-uses are cogent within The Broads Executive Area. The Broads are of high international biodiversity importance. The fen soils store and sequester significant amounts of carbon, with the carbon flux vulnerable to potential drying. The Broads also has vital importance for flood defence and water quality. The Broads Authority is working in partnership on numerous initiatives to improve landscape resilience, sustainability and ecosystem function, in order to safeguard ecosystem services (Broads Plan, Broads Authority 2011).

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[2] CSERGE Social Environmental and Economic Research programme, modelling impacts of climate change, economics and environmental policy on ecosystem services including: farm incomes, greenhouse gases, water quality, habitats, biodiversity and recreational values. http://www.cserge.ac.uk/current-research-projects/seer

[3] http://www.watergov.org/documents/Catchment_Template%204%20page.pdf

[4] http://www.environment-agency.gov.uk/static/documents/Business/Catchment_Pilot_External_Stakeholder_Briefing_July_2011.pdf

[5] http://www.lwec.org.uk/activities/demonstration-test-catchments

[6] http://www.wensumalliance.org.uk/

The need for evidence

An evidence base is required for a strategic response to issues of land-use change, climate mitigation and adaptation, sea level rise and saline incursion. The evidence base should include baseline information of resources, priorities, vulnerability and tolerance in order to allow spatial strategic decision making.

The Broads contains a diverse range of habitat types and associated species assemblages including wet fen (including reed swamp, rich fen and mire), grazing marshes and associated dyke systems, open water (shallow lakes), wet woodland, estuary and coast. Although the outstanding importance of the Broads has been recognised, no systematic audit of its biodiversity has been undertaken previously.

This study therefore sought to examine and quantify the biodiversity importance and uniqueness of differing habitats and landscape elements within the Broads Authority Biodiversity Action Plan area (covering 1,122 1-km squares), in order to provide an evidence-base to underpin conservation priorities and strategic adaptive planning. This has been achieved by an inclusive audit to inventory biodiversity and priority species, systematic analysis of habitat associations and implementation of a 'map and stack' technique to highlight key locations for biodiversity delivery.

This study also sought to examine the sensitivity of multiple species to stressors and drivers (saline incursion and flooding/droughting) in order to define assemblages of species with similar tolerances that could be subsequently mapped. This provides an evidence layer that can then be linked to saline incursion maps and climate change scenarios to support adaptive management, as proposed by the Phase 2 Strategic risk and adaptation assessment of the Proposal for Salinity, Hydrology and Climate Change Risk Assessment in the Broadland Fens (Broads Authority, August 2010)[7]. Furthermore, quantifying the Broads biodiversity assets and understanding its vulnerability to salinity and hydrological change is an important step in the development of the Broads Climate Change Adaption Plan (Broads Authority 2011).

Project Aims

1. To quantify the national biodiversity importance of the Broads.

2. To quantify the relative numbers of priority species within different Broads habitat assemblages.

3. To understand the spatial distribution of these priorities.

4. To develop methodology and framework providing evidence for the spatial distribution, tolerance and sensitivity of priority species to saline incursion and flooding.

5. To apply this methodology to map tolerance and sensitivity of priority species to saline incursion and flooding throughout The Broads Executive Area and the wider area of The Broads Biodiversity Action Plan.

[7] http://www.broads-authority.gov.uk/broads/live/authority/publications/conservation-publications/Proposal_Salinity_Hydrol_and_CC_Risk_Aug_10.doc

The Broads

The Broads, situated in Eastern England, is of international biodiversity importance for large tracts of lowland wet fen (including reedbed, rich fen and mire), grazing marshes and associated dyke systems, open water (shallow lakes), wet woodland, estuary and coastal habitats (Broads Authority Biodiversity Action Plan: Framework Document 2009) (Figure 1b). Historically, it also retained other important land-use elements including heathland, commons and weed-rich arable lands (Williams 1997).

The international importance of the Broads is emphasised by the designation of 71.4 km^2 within the Broads Authority Executive Area as Special Areas of Conservation (SAC) or Special Protection Areas (SPA) under European Directives, with wetland areas also designated under the Ramsar Convention. Almost one quarter (23 %) of the Broads Authority Executive Area is notified as SSSI (Figure A1, Table A2).

Study Area

The Broads Biodiversity Audit study area comprised those 1-km grid squares that included part of the Broads Biodiversity Action Plan (BAP) area (Figure 1 and Figure 2), which encompassed the whole of the Broads Authority Executive area, 301 km^2. The Broads BAP area is largely a single contiguous unit; isolated gaps within this were in-filled for the purposes of the audit.

Waveney-connectivity extension

The distribution of priority species recorded in the Broads was also examined in the upper reaches of the River Waveney valley, defined as 1 km either side of the length the River Waveney, up to and including Redgrave and Lopham Fens (Figure 1a). The close proximity of the Waveney headwaters to those of the Little Ouse may offer potential hydrological and ecological connectivity between the Broads and wetland habitat in the Fens bio-region. Understanding and enhancing this connectivity may be important in allowing species range shifts at regional and national scales, in response to climatic change. Although not undertaken in the present study, future work could also examine and map the distribution of wetland species recorded within the Broads further up other river valleys, e.g. Bure or Ant. Whilst these do not provide connectivity to other wetland and fen bioregions, understanding opportunities for migration upstream would provide evidence to underpin strategic responses to sea level rise and saline incursion. Furthermore, this would also provide evidence to support the Broads Authority's 'whole valley' management approach (Broads Authority 2011).

How Hill
©Ian Aitkin

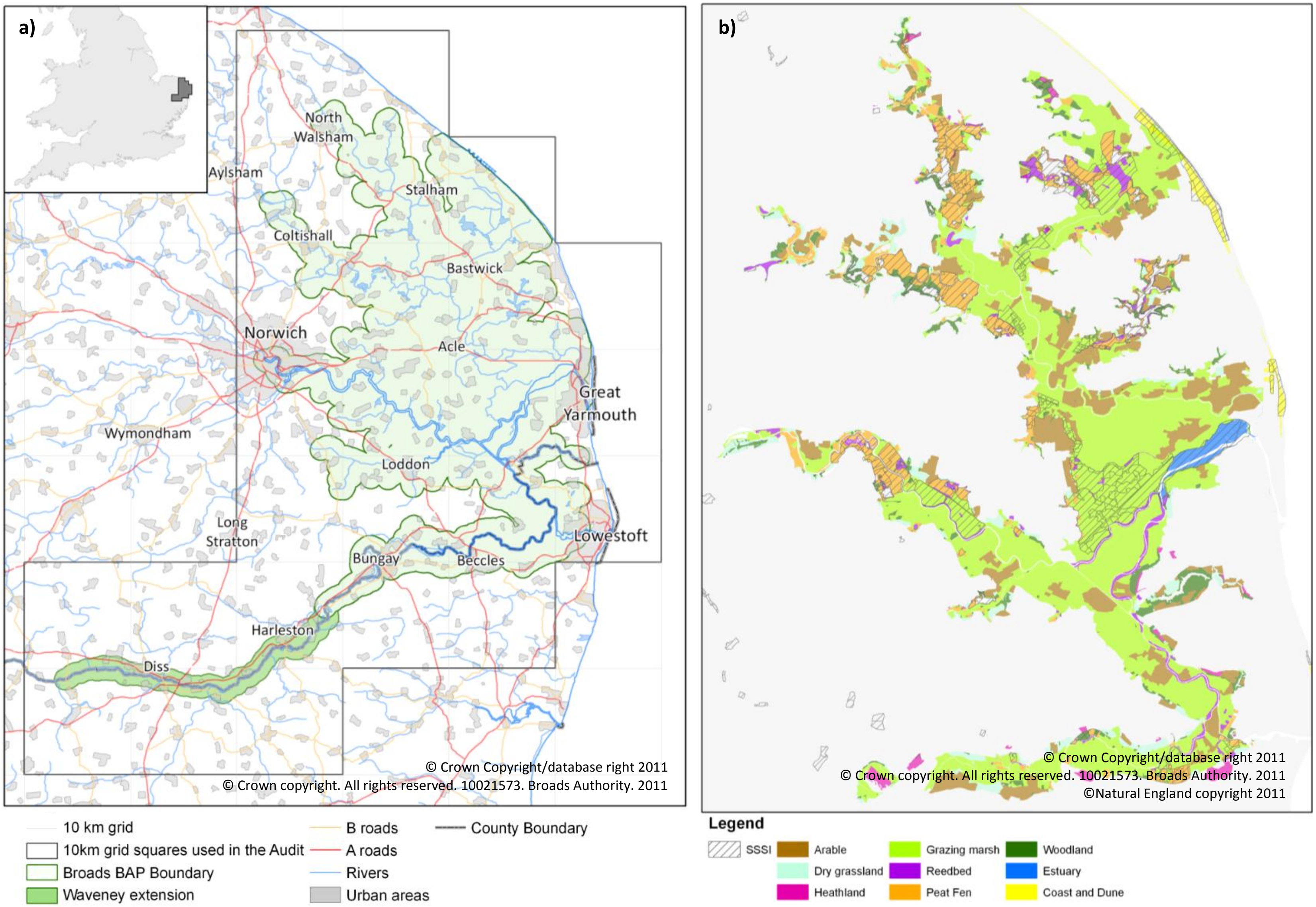

Figure 1. The Broads study area showing a) the location of the Broads within the UK (inset) and within the region, the location of urban centres, major roads (A and B roads), open water, the boundary of 10 km grid squares for which records were collated, extent of the study area (Broads BAP) and the Waveney-connectivity extension; and b) the distribution of major habitats in the Broads, defined by Broads Authority

Methodology

Collation of species records

The study area was restricted to those species occurring in the Broads BAP area and the occurrence of these species within the Waveney-connectivity extension. However, as a number of datasets were only available as aggregated units of 10-km grid squares (despite resolution greater than this) and because a small number of species records were only available at 10 km resolution, it was therefore necessary to collate biological records from a wider area, comprising the 25 10-km grid squares that encompassed the Broads BAP area or the Waveney extension (Figure 2). This methodology also provides the landscape context for the biodiversity of the Broads and an understanding of the distribution of regionally restricted priority species within this wider area.

All available records were obtained from within the 25 10-km grid squares, resulting in the collation of a total of 1,507,648 records. Species records were imported and managed using the software Recorder 6 (www.jncc.gov.uk/page-4592).

Sources of records

A full list of the sources of species records, including the number of records contributed, is provided in the Appendix Table B1.

Fifty-one percent of records collated were obtained from the Local Records Centres (Norfolk Biological Information Service (NBIS) and the Suffolk Biological Records Centre (SBRC)) (Figure 3). Fifty-nine organisations had records from the area available through the National Biodiversity Network (NBN) and all provided access to these. Records were obtained directly from the British Dragonfly Society, British Arachnological Society and Spider Recording Scheme, and British Lichen Society Records. The British Trust for Ornithology provided data from the Wetland Bird Survey (WeBS) and the Gibbons Breeding Bird Atlas (1988-1991). A number of electronic datasets were obtained from the Broads Authority, including Annual Macrophyte Surveys and records from the Fen Plant and Invertebrate Surveys (data collected in 2008 and 2007-2009 respectively, ELP 2010, Lott et al. 2010). A number of site managers and natural historians provided additional records, including the Wheatfen Partnership, Buglife's grazing marsh ditch surveys and a large number of records provided by the Balfour-Browne club. The offices of the Broads Authority, Natural England and RSPB Strumpshaw were visited to obtain undigitised records.

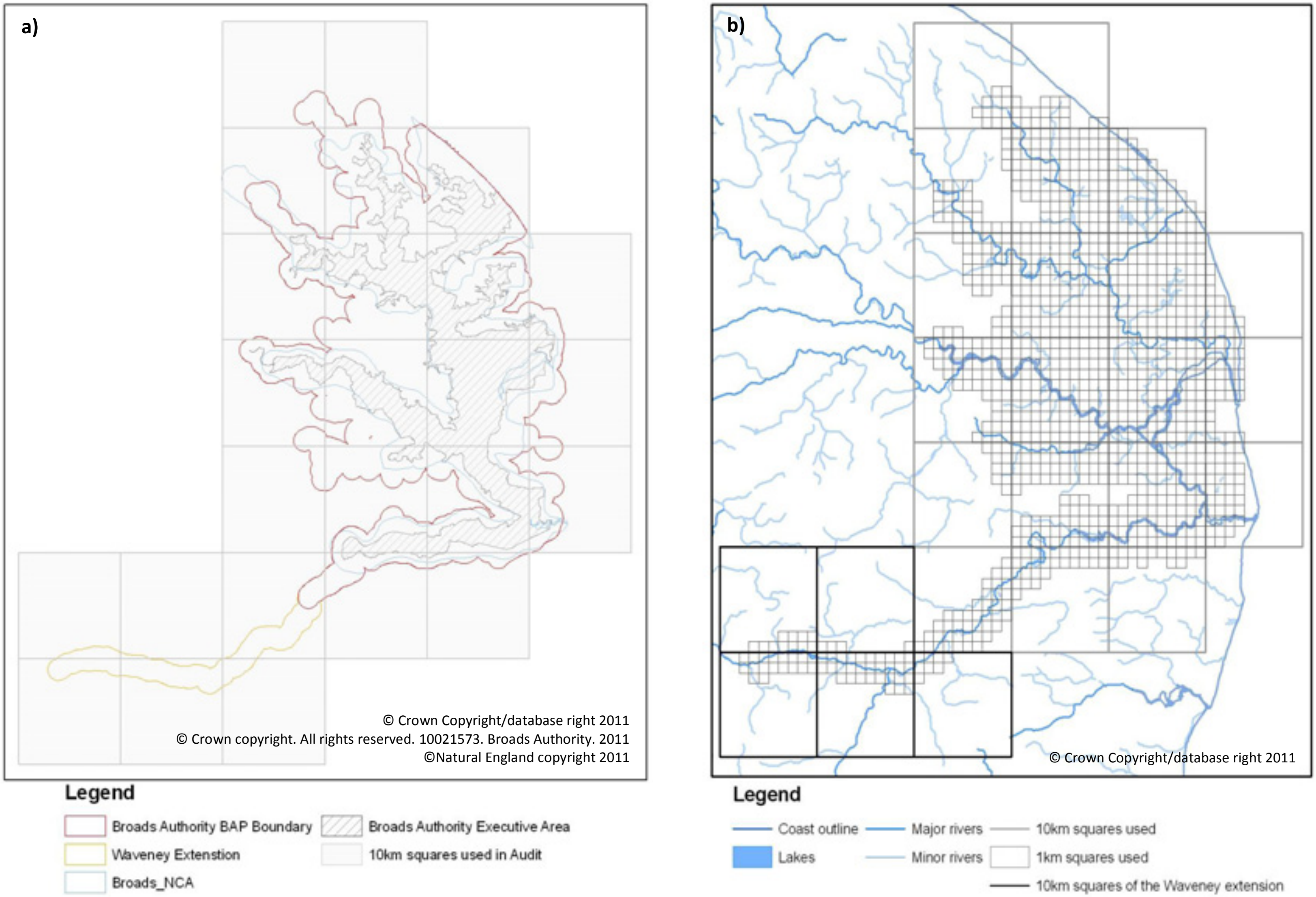

Figure 2. a) The 25 10-km squares for which records were collated, showing the Broads study area, the Waveney extension, the Broads Authority Executive Area and Broads National Character Area (NCA); b) The grid of the 1,122 1-km squares for which records were mapped

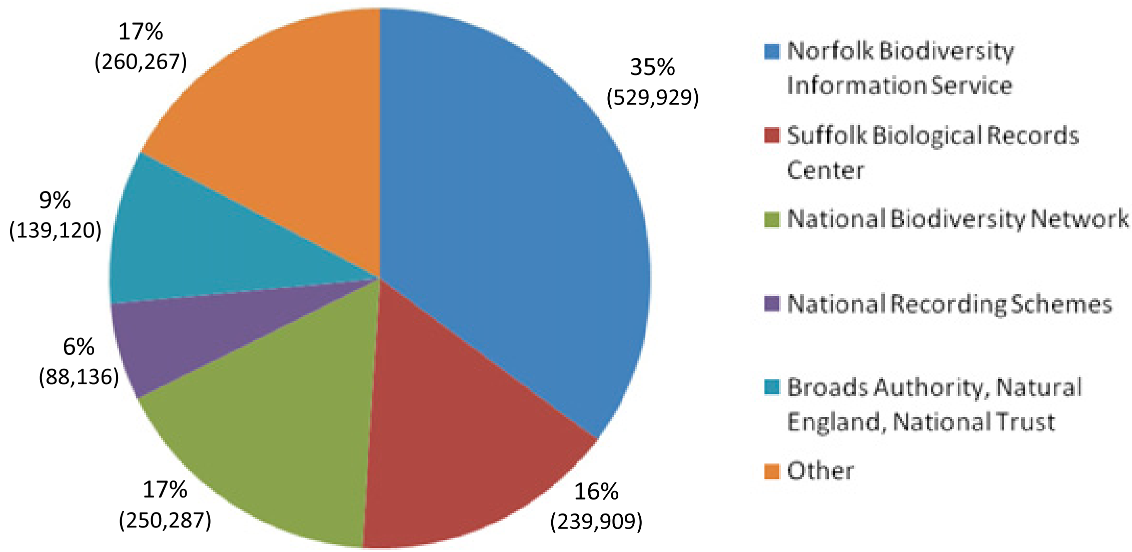

Figure 3. The proportion of records from different sources obtained by the Broads Biodiversity Audit. The total number of records collated was 1,507,648

Database refinement

The resulting database included records for 13,634 taxa. This database was subject to refinement, which comprised the following.

- The identification and removal of species not occurring in the study area (1,122 1-km grid squares comprising the Broads BAP area and 8 core 10-km squares covered by >75% of the BAP area).
- Removal of taxa not recorded to species level or finer (e.g. records to genus).
- Aggregates of micro-species were treated as a single species. Sub-species and taxon variants (i.e. seg./form./subsp./var.) were usually aggregated with the parent species, with exceptions where a conservation designation applied solely to the sub-specific taxon when these were maintained as separate taxa.
- The identification, and subsequent removal from habitat and tolerance analysis, of bird species present in the Broads only as vagrants. Such species were identified using the Norfolk Bird Atlas (Taylor and Marchant 2011). Note: It is likely that there were a number of vagrant invertebrate taxa records in the database (particularly moths), but we were not able to consistently remove such species due to insufficient information.
- The identification and removal of sub-littoral, fully marine priority species. Eleven such species were recorded within the study area, including several cetaceans and Loggerhead Turtle *Dermochelys coriacea*. These were excluded from any further analysis and mapping since they do not utilise Broads habitats. Priority marine species occurring in the area and that were considered to utilise Broads habitats (e.g. dune, rivers, estuarine mudflats) were retained. These included anadromous fish (i.e. species that have distinct marine and freshwater life history stages), estuarine invertebrates and seals.

Taxa, including designated sub-species and aggregates, are hereafter referred to as ‘species’ for simplicity.

Cut-off date

In order to ensure that biodiversity mapping was broadly representative of current species distributions, a cut-off date of 1988 (≥1988) was selected and records from before this date were not used in the mapping of contemporary priority species and current distribution of hydrological and salinity tolerance categories. This cut-off date included 83% (174,931 records) of the 210,522 priority species records collated.

Definition of conservation priority species

Following the refinement of the database, the resulting list of species was assessed against conservation designations using JNCC's Conservation Designations for UK Taxa[8].

The Broads Biodiversity Audit considered species to be conservation priorities if they had at least one of the following designations:

- BAP – all Biodiversity Action Plan priority species as in the revised 2007 list;
- Red Lists (Global and UK lists), including species listed as Extinct, Extinct in the wild, Critically Endangered, Vulnerable, Rare, Near threatened and Data deficient, but not those listed as Least Concern;
- Nationally Rare and Nationally Scarce, Notable A and B species;
- Red and Amber List birds;
- "Broads Specialities" – species restricted to the Broads region within the UK (see below for methodology and definition).

It is important to note that many taxa have more than one designation.

Definition of Broads Specialities (regional priority species)

Previous attempts have been made to list those species that, within the UK, appear to be restricted to the Broads. For example, the Broads Plan 2004 (Broads Authority 2004) recognised 13 species entirely or mostly confined to the Broads, including six plants and five invertebrates. However this was not intended as a comprehensive listing and no previous treatments of Broads Specialities has been exhaustive or used a systematic methodology.

Following methodologies developed by Dolman et al. (2010), candidate Broads Specialities were first identified using a combination of searches of published and electronic information and consultation with expert stakeholders. Their status as Broads Speciality species was then confirmed by examining quantitative information for their UK population range or abundance, recognising the following categories:

[8] http://www.jncc.gov.uk/page-3408; latest update accessed on February 2011

Species that within the UK:	Quantified information required for classification
Are **Entirely Restricted** to the Broads	100% of 10 km squares in which a species have been recorded are, or ≥50% of breeding numbers (when known), within the Broads 10km squares
Are **Largely Restricted** to the Broads	≥80% of 10 km squares in which a species have been recorded are, or ≥50% of breeding numbers (when known), occur within the Broads 10km squares
Have a **Primary Stronghold** in the Broads	≥50% of 10 km squares in which a species have been recorded are, or ≥50% of breeding numbers (when known) occur, within the Broads 10km squares

Locally extirpated and nationally extinct species for which historic records were made in the Broads (Table 8) were considered as candidate Broads Specialities if their historic UK distribution met the relevant criteria.

Expert stakeholder validation of collated priority taxa

The current status of priority species and their occurrence in the area was validated using all sources of species information that informed habitat and tolerance assessments. All BAP species were also validated for their presence in Norfolk using the Norfolk Biodiversity Action Plan Species Data Audit (NBIS 2008).

The provisional lists of conservation priority species were sent to approximately 40 experts for validation in order to identify erroneous records, likely misidentifications, species now considered historic to the region (i.e. locally extirpated or nationally extinct) and candidate Broads Speciality species. Most taxonomic groups were successfully validated in this way, with the exception of fungi, non-aquatic Coleoptera (for which a random selection of species were validated and experts are continuing to inspect the list), mosses (experts are currently working through the list) and Diptera, for which we have no expert currently available to validate.

Seventy-two species were identified as garden-escapes, erroneous, misidentifications and invalid taxon names (e.g. species that have been reclassified but both old and new names existed in the database) (Table A5) and were excluded from further analysis.

Extinct and Extirpated taxa

Mapping of priority species, vulnerability and tolerance was conducted only for those species for which recent records (i.e. ≥1988) had been collated. Numbers and identity of priority species were compared between the entire data set and those restricted to recent years in order to identify those priority species for which historic but no recent record existed. These will include genuinely extinct or extirpated species.

Taxa that were considered to now be either locally extirpated or nationally extinct, but which were previously recorded in the Broads, were identified as:

- those listed as Red Data Book Extinct,
- those listed in Natural England's Lost Life publication (Brown et al. 2010),
- those indicated as extirpated by taxonomic experts.

For each of the taxa identified as regionally or nationally extirpated, the date of the last record collated by the Biodiversity Audit was identified (see Table 8). A number of species showed discrepancy between the last recorded dates stated in the Lost Life report and those in the Audit database; reasons for these differences are provided in the section, Findings of the Audit.

No attempt was made to carry out a similar collation and quantification of all non-priority species for which no recent (post-1988) record is known.

Collating and Synthesising Species Habitat Associations and Tolerances

Habitat associations of conservation priority species were assessed in relation to 31 broad habitats (e.g. reedbed, heathland, wet woodland etc.) and six key micro-habitats (e.g. clear water, deadwood, poaching etc.). These were derived from the broad habitats listed by the LandCoverMap2000 (Fuller et al. 2002), modified from previous experience (Dolman et al. 2010) to be appropriate for assessing species requirements, and using expert knowledge and discussion with the Steering group (full list is provided in the Appendix Table B2).

All conservation priority species were assigned to every habitat and micro-habitat classes in which they were known to occur and were not constrained to a single habitat. Habitat associations were graded as; 1) primary habitat(s) (i.e. evidence states that the taxon is primarily or most frequently recorded in, or associated with, this habitat) and 2) secondary habitat(s) (i.e. species is occasionally recorded in, or associated, with this habitat - as indicated, for example, by a statement that species are "also known from" the habitat). The classification of primary versus secondary therefore has a degree of subjectivity, but was consistently applied, with just one person (Chris Panter) classifying all species.

Habitat associations were identified using a wide range of sources of ecological information. The largest of these was the species accounts stored within Recorder 6, which includes species accounts developed from the Invertebrate Site Register, various Red Data Book accounts and checklists, and reviews of taxonomic groups. This information was supplemented by other literature and expert opinion. A full list of sources is given in Appendix Table B3.

A wide range of information was used to assess species sensitivity to flooding and salinity (for classification see below). These included all sources used to assign habitat associations, plus further relevant information that included:

- Inference of sensitivity from the presence at sites of known salinity, elsewhere in UK and Western Europe.
- Buglife lists of notable species associated with different habitats.
- Ecological information:
    - Ellenberg values for plants (used for priority plants and, with caution, for priority invertebrates with associated host plants)
    - Buglife’s coding of salinity tolerances of 2000+ species (Palmer et al. 2010)
    - Linked species and environmental data from the above Buglife data and also the Broads Fen Invertebrate Survey (Lott et al. 2010)
    - Water level requirements for a large number of plants (Newbold 1997)
    - WoRMS (World Register of Marine Species).

The use, quality and interpretation of these sources are discussed in the Technical Report.

Tolerances of species to salinity and hydrological changes

All conservation priority species occurring in the study area, with the exception of gull species (family Laridae; 10 species), were considered for their tolerance/vulnerability to salinity and hydrological change, including both flooding and droughting sensitivity.

Species were classified according to their *maximum tolerance to salinity*, i.e. the *upper* salinity limit of their tolerance. This followed a consistent and systematic methodology, making use of a number of sources of evidence for tolerance, primarily from known distributions of species (including information from Recorder Statements and lists of species at sites of known salinity). In addition, for plants, salinity tolerance was also obtained from published Ellenberg values, which are widely used and well considered indicators of salinity. There are two areas of uncertainty in these methods:

1) Some species may have been attributed to an incorrect category. However, we believe that most species were correctly coded, and were able to independently validate the classification of a sub-set of invertebrates (testing 75 species) as a measure of accuracy (see below).
2) Although we are confident that species of a given salinity category will not tolerate consistently higher (or in some cases lower) salinities, an important area of uncertainly arises from the extent to which species could tolerate brief episodes of higher (and in some cases lower) salinity. Species tolerance of such episodes will depend on the frequency and intensity of saline incursions and the duration and persistence of the raised salinity, which in turn will be affected by hydrological characteristics of individual sites and the timing of the episode in relation to vulnerable or resistant life history stages. The information currently available is insufficient to assess this. The methodology used in this study, therefore, provides an understanding of the distribution of vulnerable priority species, predicts that persistent or repeated saline incursion would deplete intolerant assemblages, but cannot quantify the proportion of species depleted by infrequent and ephemeral incursions.

In contrast, the tolerances of species to hydrological changes was inferred from best available evidence for aspects of species (or occasionally a wider taxon category, e.g. family, genus) life history, ecology and natural history, including the distribution of species in relation to prevailing conditions. Similarly to saline tolerances, the effects of rapid hydrological change will depend the season and corresponding life cycle stage, and the water quality, duration and persistence of the conditions. We were unable to locate information for known species responses to episodes of drying or flooding. As a result, the confidence that can be placed in these hydrological tolerances is reduced. We consider the classification provisional and welcome further input from species experts.

Tolerance to changing hydrological conditions

The conservation priority species were assessed for their tolerance/vulnerability to changing hydrological conditions, considering sensitivity to both flooding and droughting scenarios, and assigned to one of seven categories (Table 1). Further details on the relationship between the hydrological categories used by the Broads Audit and those published by other authors, e.g. Ellenberg values, are given in the Technical Report.

Table 1. Categories used in the Broads Biodiversity Audit to assess species for their sensitivity to hydrological change

	Flooding Scenarios	Droughting Scenarios	Typical habitats	Description and typical taxonomic groups
1	Very High vulnerability	Beneficial/No negative consequences	Woodland, grassland, heath, arable	Dry terrestrial species (can include species of river shingle) Vulnerable to flooding, droughting is N/A)
2	Very High vulnerability	Moderate vulnerability	Damp grassland, damp woodland (not carr)	Species of damp habitats
3A	High Vulnerability (less vulnerable than damp)	Some vulnerability (less vulnerable than 3 as spp. can move with edge of drawn down zone, but prolonged drought results in complete loss of water body)	Littoral margins, wet edge, seasonal fluctuations of ponds/ lakes/ rivers/ riparian sand/ shingle bank	Species of wetland habitats, with no aquatic lifecycle and no explicit requirement for open water. **Shallow-rooted marginal species**. Including fluctuating water *(Category is different from* littoral habitat*, which can include aquatic or part-aquatic spp. (Categories 4 &5) using submerged littoral edge)*
3	Vulnerable (as wetland species therefore open water is likely to be common, even if species is not using open water, therefore likely to have wet adaptations as opposed to the more terrestrial sp in 3a using the marginal habitats)	Some/High vulnerability	Fen, wet grassland, carr	Wet habitats typically with standing water (not necessarily an explicit requirement for water. Though can include semi-aquatic larva, which can exist in damp/wet soil or tiny ephemeral pools e.g. species of **long-legged flies** (**Dolichopodidae**)
4	Very High tolerance and some benefit (depending on flow, quality and depth)	Very High vulnerability	Standing or flowing water: lakes, rivers but also other wetland habitats e.g. fen	Fully aquatic species. Includes species that are fully aquatic through entire life (**fish**, some **aquatic invertebrates**) or almost entire life (e.g. **mayflies, stoneflies and some of the more fully aquatic water beetles**)
5	High tolerance and some benefit (depending on flow and quality) – *larvae/pupa/ overwintering adult stages likely to more tolerant of flooding than those in Cats 4-2*	Some vulnerability	A variety of habitats from small scale ditch species to landscape scale open water/wet fen and grassland mosaic	*Part-aquatic (life-cycle):* May have aquatic life history stage, but also requires some damp/litter/edge above the water table. Can include species of shallow pools, wet ditches and littoral edge. **dragonfly, amphibians, water beetles – no plants**
6	Mixed consequences (wet habitats may benefit, dry habitats are vulnerable)	Some vulnerability (wet habitats used vulnerable, N/A to drier habitats)	Large variety, but includes wetland and dry terrestrial	*Part- aquatic (landscape scale):* Species operating on landscape scale. **Hymenoptera or vertebrates** may be typical

Tolerance of salinity

Conservation priority species were assessed and coded for their tolerance of raised salinity if they were coded in hydrological tolerance categories 3-6. These were typically species:

- primarily associated with wetland and aquatic habitats (e.g. salt marsh, carr, fen, bog, wet grassland, reedbeds, pools, lakes, rivers)
- or that have aquatic life stages,
- or that are phytophagous on aquatic or fen plant species

Priority species solely associated with dry terrestrial habitats such as heathland, or damp habitats such as damp grassland (i.e. hydrological tolerance categories 1 and 2) were not assessed for their saline tolerance.

Species were classified according to their *maximum tolerance to salinity*, i.e. the *upper* salinity limit of their tolerance, into four groups, shown in Table 2. For a sub-set of 75 species, classification of salinity tolerance categories using the methods adopted in the Audit was validated by comparison with independent classification by Palmer et al. (2010). Eight-one percent of species validated were classified into similar categories by this Audit and by Palmer et al. (2010). Further details on the relationship between the salinity tolerance categories used by the Broads Audit and those published by other authors, e.g. Ellenberg values, Palmer et al. (2010) are given in the Technical Report.

Table 2. Salinity tolerance categories used in the Broads Biodiversity Audit, based on ‰ salinity of Venice System for the Classification of Marine Waters According to Salinity (Anon, 1958). Chloride concentrations were converted from ‰ salinity using Broads Authority (2010). Corresponding conductivity values for categories are based on the Venice system and are not specific to the Broads

Audit scores	Category	Description	Typical Habitats	Chloride (mg/l)	Conductivity (µS/cm)
1	Freshwater	Freshwater, i.e. intolerant of saline waters, cannot tolerate even slightly saline or brackish conditions and therefore highly vulnerable to any saline incursion. Species of unknown tolerance	Freshwater lakes and rivers	<300	<800
2	Slight saline influence	Tolerant of slight saline conditions. Often "freshwater" species, but evidence of tolerance of occasional increases in salinity or lightly brackish (can include species more usually found in freshwater conditions).	Rivers, grazing marsh, fen	300-3,050	800 - 7,800
3	Brackish (Mild to moderate)	Species tolerant of brackish conditions (can include species more usually found in freshwater conditions with evidence of brackish tolerance).	Stretches of tidal rivers, dykes in coastal grazing marsh	3,050-11,000	7,800 - 28,100
4	Saline	Tolerant of fully saline conditions. Saline/highly brackish species, including hypersaline (e.g. salt marsh pools) and highly saline estuarine/marine species.	Saltmarsh, marine	>11,000	>28,100

Data Mapping and Analysis

Data resolution

Of the 1.5 million records collated, 25% were recorded at a resolution of less than 1 km, including 177,898 recorded as tetrads and 202,816 recorded at 10 km resolution. All maps showing numbers of species or records were created using records at 1 km resolution or better. Tetrads records were "ungrouped", by converting into four 1 km records, and were subsequently used in mapping. Due to poor resolution, species records at 10 km resolution were not used in mapping. Eighty-six priority species were only recorded at 10km resolution within the study area and consequently were not mapped. Nineteen of these were identified as extinct or locally extirpated species and one other was a regional speciality, *Carex trinervis*.

Mapping

Category bands used in mapping were usually defined by geometric intervals; these are appropriate for non-normally distributed data, which can be heavily skewed. Maps showing smoothed surfaces of data were created by the Inverse Distance Weighting method.

Mapping salinity gradients

River salinity
Electrical conductivity is a generally accepted method of quickly and cheaply measuring salinity. To investigate the utility of conductivity as a proxy, we examined the strength of the relationship between conductivity and salinity.

Environment Agency water conductivity data for the period of 1990-2010 were collated from 12 sampling stations on rivers in the Broads, and initially were compared to species tolerance categories. However, in the Broads relationships between conductivity (µS/cm) and salinity are complex and may be site-specific. The relationship between chloride concentration and conductivity were investigated by at Honing Lock and Brograve Pump with data collected on the same day available for 91 and 87 days respectively, during the period 1990-2010. In moderately to strongly saline influenced areas (e.g. at Brograve Pump) there are strong relationships between chloride and conductivity (Figure 4), because Na^+ and Cl^- are the dominant ions; in these areas therefore conductivity is a suitable proxy measure for salinity. However, in the upper reaches of some rivers with little saline influence (e.g. at Honing Lock), other ions, such as nitrates and carbonates, make significant contributions to the conductivity and there are weak relationships between salinity and conductivity; in these circumstances conductivity is a poor measure of salinity. In contrast, for conductivities greater than 1000 µS/cm the strong relationship between conductivity and salinity validates its use as a proxy.

Although conductivity is a fast and cost-effective method of measuring relative salinity and is likely to be an appropriate measure to detect major saline events, it should not be used to monitor for small changes in salinity. The relationships discussed above are based on the relatively few available measurements that were collected on the same day. The relationship between chloride and conductivity measurements that were collected within five days of one another showed more variation, particularly at Horning Lock. It is therefore recommended that the availability of comparative data be investigated and further work be carried out to better understand the relationships between conductivity and chloride at different locations and to assess the thresholds at which the relationships have sufficiently small errors to be useful. This should also include consideration of other sources of chloride in the catchments. Other proxy measurements of salinity, such as chloride ion selective electrodes, could also be investigated.

In order to investigate the spatial distribution and frequency of saline incursion events in the Broads, river systems, chloride data, as a proxy for salinity were examined. Environment Agency water chloride data for the period of 1990-2010 were collated at 10 sampling stations on rivers in the Broads. Chloride data were largely available as chloride ion mg/l; three sites (Catfield Pump, St Benets Abbey and Brograve Pump), supplemented with chloride GFC mg/l data. These data were analysed as time series and mapped to visually represent the spatial and temporal variability of salinity, with categories of biodiversity tolerances overlain.

Grazing Marsh salinity

Four water conductivity datasets from grazing marsh ditches and dykes were collated, covering three periods (NE: 1975-1976; NE: 1997; BESL and BA data: 2001-2008); chloride measurements were not available. The 2001-2008 data were used to understand the current environmental conditions in the ditches and allow comparison to the mapped salinity tolerances of species. The older datasets were collated to explore potential temporal changes in salinity within grazing marsh ditches. It should be noted that the salinity of grazing marsh ditch systems is known to be highly variable, with complex interactions between isolated freshwater upwellings and seasonally variable, saline influenced river-courses.

The sources and methodologies used for both the river chloride and grazing marsh conductivity measurements and distribution of data points is discussed in the Technical Report.

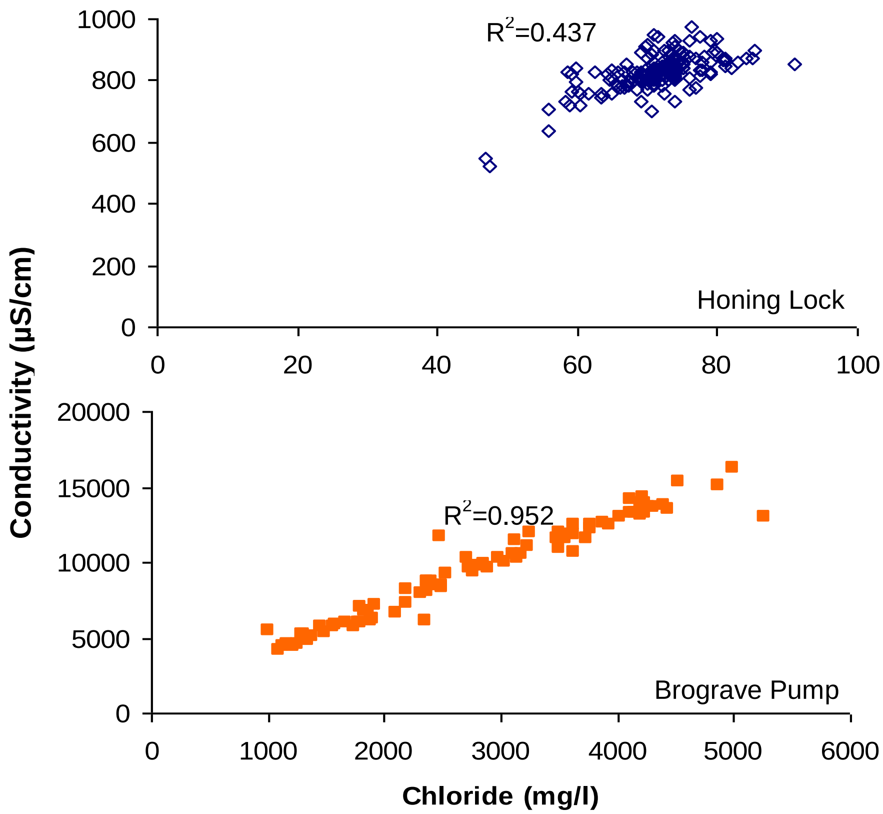

Figure 4. Relationships between chloride (mg/l) and conductivity (µS/cm) at two sampling locations within the Broads. Sampling locations are mapped in Figure 15

Findings of the Audit

Taxonomic coverage of data collated from the wider Broads area

There was considerable taxonomic bias in recording (e.g. Figure 6). For example, Lepidoptera and Chara were well recorded, in contrast to poorly represented groups such as snakeflies (only 6 records were received) and stoneflies (25 records). Soil macro-infauna were very poorly recorded. Few records were received of plankton, though we are aware that further un-collated data exist, e.g. the late K. Clarke's extensive records of phytoplankton (particularly diatoms), as well as records from BA, National Rivers Authority and EA of zooplankton and phytoplankton data for selected lakes, which were not collated. Further information on recording bias and taxonomic coverage of data and accompanying table of records per taxonomic groups is given in the Technical Report.

Geographic coverage of records

The intensity of biological recording was high in the northern areas of the Broads (Figure 5). However, the southern area of the Broads BAP was generally less well recorded and lacked notable recording hotspots. Hotspots of recording effort generally reflected the location of SSSIs (Figure 5a, b). Some 1-km square hotspots (in terms of raw numbers of records, Figure 5a) are the locations of regular moth traps, with >95% of records in these squares comprising moths. However, when effort is considered in terms of the number of taxonomic groups represented per grid square (Figure 5b), these areas are no longer hotspots of recording.

Examining the spatial distribution of recording intensity separately for different major taxonomic groups (Figure 6), emphasises the very restricted nature of recording effort. It has largely focused on a very small proportion of the habitat resource, particularly in the fens of the Ant, Thurne, Bure and Mid-Yare. For groups such as spiders, true bugs, beetles and true flies, large parts of the Broads BAP area are unrecorded (Figure 6). This represents a limitation in the evidence base.

One particularly notable area of poor recording, particularly as it includes areas of SSSI, was the Halvergate Marshes to the west of Breydon Water (including South Walsham Marshes, Acle Marshes and Beighton Marshes) – an area of variable salinity (Figure 14). Poor recording effort is likely to be due to the restricted access to the marshes. There would be considerable benefit from increased recording intensity in these areas, particularly considering the biodiversity value of similar areas of grazing marsh, e.g. to the south of Breydon water.

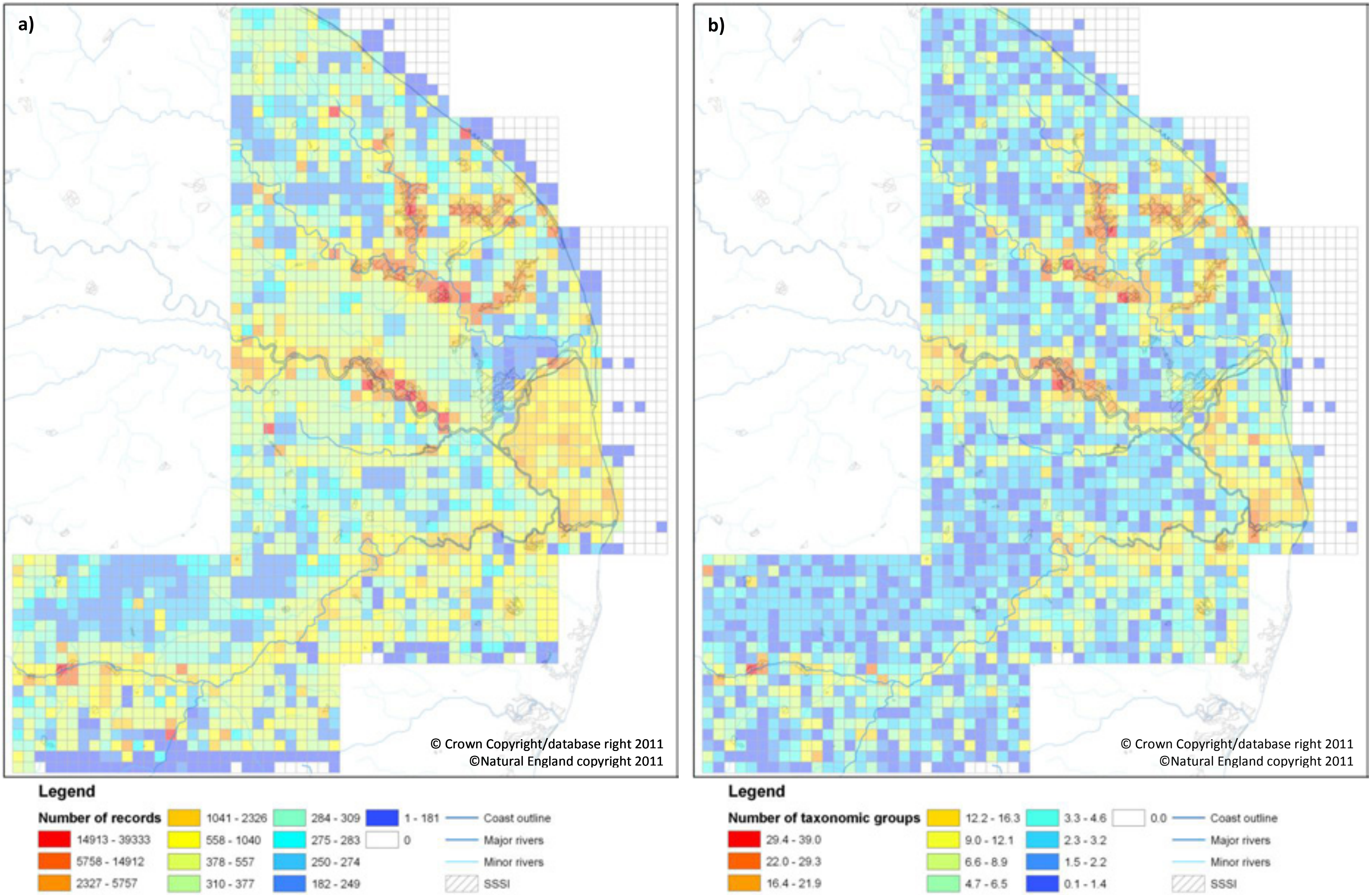

Figure 5. Recording intensity: a) number of records per 1km square b) number of taxonomic groups per 1km square in the Broads wider area based on all records at a 1km or greater resolution and tetrad records. The total number of records shown is 1,832,601 records, including those pre- and post-1988. Bands for categories are determined by geometric intervals

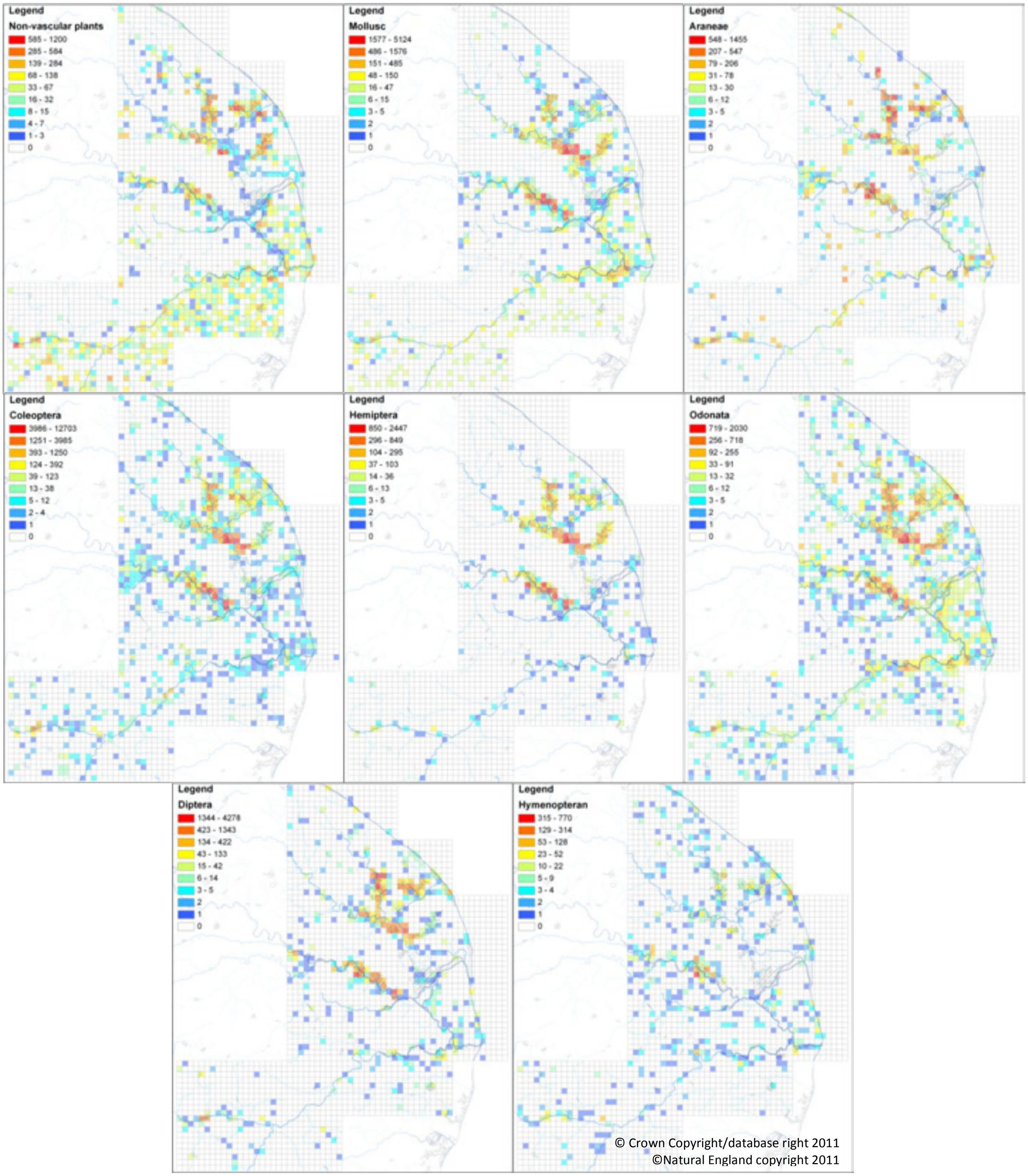

Figure 6. The variability in recording coverage in the Broads for non-vascular plants (Bryophytes, Algae, Characeae), molluscs, spiders (Araneae), beetles (Coleoptera), true bugs (Hemiptera), dragonflies (Odonata), true flies (Diptera), bees, ants and wasps (Hymenoptera). These maps exclude tetrads records

The Broads Biodiversity

The Broads region is very important for biodiversity, with records (pooling pre- and post-1988) comprising:

- 11,067 species in total
- 1,519 priority species (GRDB, RDB, Nationally Notable, Birds of Conservation Concern, BAP, regional specialties) (Table 3).
- 19% of total designated species in the United Kingdom (based on the JNCC only), occurring in an area only 0.4% of the United Kingdom.
- 26% of the UK's BAP species, 13% of the UK's RDB, 17% of Notable and Scarce.
- Nineteen Global Red Data Book species
- A very wide range of taxonomic groups: e.g. 403 species of beetle, 251 species of flies (Diptera) and 179 species of moth (Table 4).
- Very large numbers of priority bird species – 85% and 94% respectively of UK Bird: Red and Bird: Amber designated species.
- 66 Broads Speciality species, 14 species entirely and 17 largely restricted to The Broads in the UK and 35 that have a primary stronghold in the region.

The majority (77%) of designated species recorded in the Broads are RDB or Notable (these include species designated as GRDB, RDB, Notable, Rare/Scarce).

Global Red Data Book species
The 19 Global Red Data Book species occurring in the Broads included six species of birds (although two species are vagrants to the area), four species of mollusc, the White-clawed Crayfish, *Austropotamobius pallipes* (GRB:EN, BAP) and a Hairy Fungus beetle, *Pseudotriphyllus suturalis*, a recent addition to the IUCN Red Data Book. The Medicinal Leech *Hirudo medicinalis* (GRDB:NT, BAP) is also listed, but was last recorded in 1981.

Marine: Near Scarce
Only one Marine: Near Scarce species was recorded in the Broads (Table 3), the Tentacled Lagoon Worm *Alkmaria romijni* (M:NS). This annelid has been recorded at a number of scattered southern locations from the Humber to Pembrokeshire, inhabiting lagoons and sheltered estuaries, and was found in Breydon Water, near Reedham Marshes. Although the last record was in 1987, marine and estuarine species are under-recorded and it may still be present in the area.

Broads Regional Specialities

In the first systematic assessment of its kind, sixty-six species were identified as being Broads Specialities: species for whom the region is key to their UK population (Table 5). Fourteen species were found to be entirely restricted to the Broads in the UK, including three true bugs (Hemiptera) and three true flies (Diptera), for example the Bure Long-legged Fly *Dolichopus nigripes*. A further seventeen species were identified as largely restricted to the Broads in the UK. These included two species of predaceous diving beetle and two species of moth. The remaining 35 Broads Speciality species were classified as having a primary distribution stronghold in the Broads and included eight beetle and six moth species. Whilst extensive, this assessment may not be exhaustive and further speciality species may still come to light.

Broads Specialities included five species now thought to be nationally extinct or locally extirpated. These the Norfolk Damselfly *Coenagrion armatum* (Largely Restricted) and the less well recognised semi-aquatic weevil *Lixus paraplecticus* (Primary Stronghold), which was previously found in a range of wetlands, typically fens and the littoral margins of rivers and lakes, and is associated with semi-aquatic Umbelliferae, especially water-parsnip *Sium latifolium* and fine-leaved water-dropwort *Oenanthe aquatica*, with its larvae feeding in the stem (Hyman and Parsons 1992).

Ninety-one percent of the Broads Speciality species had at least one conservation designation. The six regional endemics identified by this Audit that currently lack any designation should now be considered on the same level of importance as other conservation priorities. These species are a water boatman *Sigara longipalis*, a snail killing fly *Sciomyza testacea*, the Fen Bent-wing *Pseudopostega auritella*, a parasitic fly *Trigonalis hahnii*, an Ichneumoninae *Trogus lapidator* and a leaf-mining fly *Phytomyza thysselinil*, the latter two have not been recorded since 1988. The currently undesignated Broads Speciality moth the Fen Bent-wing is a proposed RDB Endangered (pRDB1 www.hantsmoths.org.uk/species/0120.php). It is known from many countries of the Eastern Palearctic ecozone, but is rare in the UK being only recorded from the Ranworth and Barton areas and at Wicken Fen, Cambridgeshire. It occurs in fens and broads, and it's host food plant is thought to be Marsh Marigold *Caltha palustris.*

The Broads is of national importance to the UK Bittern *Botaurus stellaris* population. Although 13 booming males were recorded in the Broads in 2010, following national population recovery, this represented 15% of the 87 booming males in UK (Wotton et al. 2010), below our criteria of a primary stronghold (≥ 50 %).


Bittern
© Brian McFarlen

There are thought to be a number of subspecies/variants of the aggregate species Intermediate Bladderwort *Utricularia intermedia* (RDB:DD), but information on the species is poor. Expert opinion indicated that no subsp/variants of the aggregate species are restricted to the Broads (Fred Rumsey Natural History Museum, pers. comm.) and it was therefore not given Broads Speciality status. However, Intermediate Bladderwort populations in the Broads are of national significance.

The Hemiptera *Polymerus vulneratus* (RDB: EN) was recognised as a species with a Primary Stronghold in the area. However, the only record of this species in the area is at a 10 km resolution in grid square TG50 that only includes a small area of the Broads BAP. The species has been found on sand dune and in brownfield sites in Great Yarmouth, but is thought to be locally extirpated, with the last record in 1954. However, the low recording effort for Hemiptera generally across the study area means unreported populations could potentially persist.

The Fen Raft Spider *Dolomedes plantarius* (RDB:EN, BAP) has been classified a Broads Speciality (Primary Stronghold). It is currently found entirely within the Waveney extension with the exception of records at one site within the Broads, following reintroduction in 2010.

One additional species, the jumping spider *Neon valentulus* (RDB: VU), was recognised as a species with a primary stronghold in the Waveney extension, but <u>not</u> occurring within the Broads. It was not, therefore, given status as a Broad Speciality, but does warrant special consideration in the wider region.

Swallowtail larvae
© Andrea Kelly

Swallowtail
© Brian McFarlen

Milk-parsley, *Peucedanum palustre,* is restricted primarily to the Broads within the UK. It grows in permanently damp tall herb fen, but can also be found in fen scrub and fen carr. It is found on peat or peat-like substrates, particularly on sites that flood in winter (Meredith and Grubb, 1993). Milk-parsley is best known as the larval foodplant for UK's largest native butterfly, the Swallowtail butterfly *Papilio machaon*, whose entire breeding population is restricted to the Broads. It is less well recognised however, that a wider food-web of priority species is reliant on milk-parsley and associated species. The ichneumonid wasp *Trogus lapidator* is a parasite of Swallowtail butterfly larvae, and is therefore also entirely restricted to the Broads. The larvae of the fly *Phytomyza thysselini* mine only the leaves of Milk-parsley and the species has a restricted distribution in the UK (Primary Stronghold). The leaf mining fly was discovered as new to Britain in 1983 from the Norfolk Broads, but currently remains undesignated due to its recent discovery and uncertain status in the UK.

Table 3. The total number of priority species with different designations that were recorded in the Broads and those species recorded post-1988. The total number of species is compared to the total UK list of designations (JNCC, 2011). Designations not listed by JNCC are provided in the Technical Report

	Total no. of species	No. of species recorded post-1988	Total no. of species in the UK	% of UK total designated taxa occurring in the Broads
Bird: Red	52	52	61	85.2
Bird: Amber	119	119	126	94.4
Biodiversity Action Plan	301	221	1150	26.2
Global Red Data Book	19	14	149	12.8
Red Data Book	491	319	3829	12.8
Marine: NS/NR	1	0	115	0.9
Notable and Scarce	757	506	4552	16.6
Total number of designated species (JNCC only)	1466	111	7798	18.8
Other designations (not listed by JNCC)	47	30		
Broads Specialities	66	54		
Total priority species recorded	1519	1096		

Table 4. The total number of priority species of different taxonomic groups recorded in the Broads (pre- and post-1988) and those species recorded post-1988

Taxonomic group	Total no. of species recorded	Species recorded post-1988	Taxonomic group	Total no. of species recorded	Species recorded post-1988
Fungus	22	7	Cockroach (Dictyoptera)	1	0
Lichen	29	17	True bug (Hemiptera)	47	34
Stonewort	15	12	Beetle (Coleoptera)	403	246
Liverwort	9	4	Caddis fly (Trichoptera)	9	4
Moss	23	14	Butterfly	17	12
Clubmoss	1	0	Moth	179	144
Fern	4	4	True fly (Diptera)	251	173
Flowering plant	183	127	Hymenoptera	60	49
Mollusc	12	10	Bryozoa	1	1
Annelid	2	0	Jawless fish (Agnatha)	2	1
Spider (Araneae)	36	28	Bony fish (Actinopterygii)	6	3
Crustacean	4	2	Amphibian	3	3
Mayfly (Ephemeroptera)	1	0	Reptile	4	4
Dragonfly (Odonata)	5	4	Bird	176	176
Stonefly (Plecoptera)	1	1	Marine mammal	1	1
Orthopteran	4	2	Terrestrial mammal	13	12
Earwig (Dermaptera)	1	1			
			Total	**1519**	**1096**

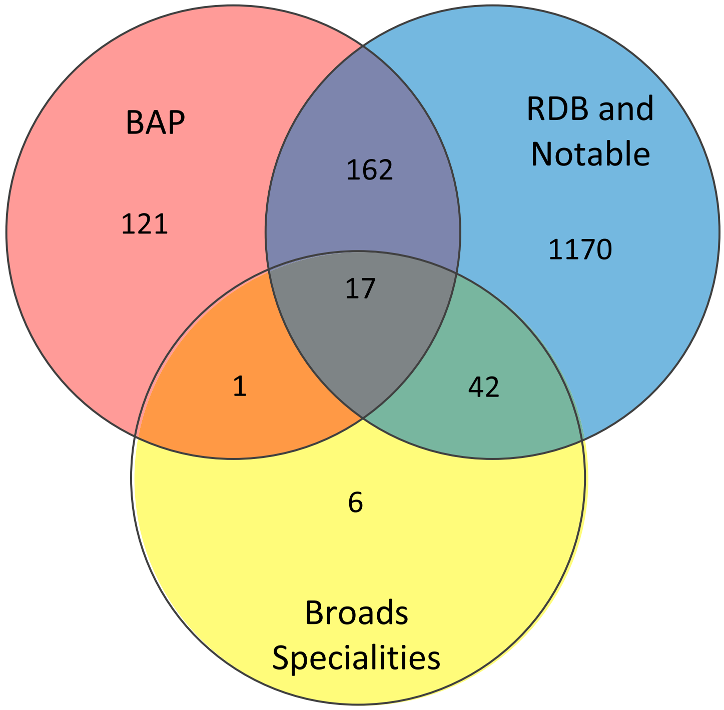

Figure 7. Overlap in the designations of the total number of species recorded in the Broads (i.e. no cut-off date applied). RDB and Notable species include RDB, Notable, Nationally Rare/Scarce and Bird: Red/Amber, both from JNCC and other sources

Biodiversity Action Plan (BAP) designated species comprise a relatively small proportion of the total priority species (Figure 7) and only 26% of Broads Speciality species are also BAP designated. However, BAP species often receive large proportions of the conservation focus and resource. They could act as indicators for wider biodiversity, but only if they are representative both taxonomically and across the full range of habitats. However, previous work has shown that, particularly in wetland habitats, assemblages of priority species are relatively poorly represented by BAP species (Dolman et al. 2010).

The fen raft spider *Dolomedes plantarius* is very rare in the UK, designated Red Data Book Endangered and BAP, and was only found at three locations, Redgrave and Lopham Fen, Pevensey Levels and South Wales. In 2010, 2800 spiderlings were released at Castle Marshes on the River Waveney, approx 50km downstream from Redgrave and Lopham Fen, in order to establish a new population. www.dolomedes.org.uk

Table 5. List of species identified as being regionally restricted to the Broads – Broads Specialities. Species not coded for tolerances are shown by 'x'. Asterisk denotes species only recorded at 10km resolution. Accepted species English common names are shown in bold. Species for no recent (post-1988) records were obtained are indicated with 1, with species confirmed as extirpated during the audit also marked with †

Taxon group	Latin Taxa Name		Designation	Hydrological tolerance score	Salinity tolerance score	Locally extirpated species or not recently recorded species
		Entirely restricted				
Stonewort	*Chara intermedia*	**Intermediate Stonewort**	RDB:EN, BAP	4	3	
Flowering plant	*Carex trinervis**	**Three-nerved Sedge**	RDB:EX	x	x	1†
Flowering plant	*Najas marina*	**Holly-leaved Naiad**	RDB:VU, S:NR, BAP	4	2	
Spider	*Robertus insignis*	Comb-footed spider	RDB:EN	3	1	
True bug (Hemiptera)	*Macrosteles oshanini*	Leafhopper	RDB:Insu	2	0	
True bug (Hemiptera)	*Metalimnus formosus*	Leafhopper	RDB:Insu	3	1	
True bug (Hemiptera)	*Sigara longipalis*	Lesser water boatman		4	1	
Butterfly	*Papilio machaon*	**Swallowtail**	RDB:NT	3	1	
Moth	*Pelosia obtusa*	**Small Dotted Footman**	RDB:EN	3	1	
True fly (Diptera)	*Dolichopus nigripes*	**Bure Long-legged Fly**	RDB:EN, BAP	3	1	
True fly (Diptera)	*Platypalpus pygialis*	Dance fly	RDB:DD	3	3	
True fly (Diptera)	*Thrypticus smaragdinus*	Long-legged fly	RDB:DD	3	1	
Hymenoptera	*Trogus lapidator*	Parasitic wasp		3	1	1
Bird	*Grus grus*	**Common Crane**	B:R	5	2	
		Largely restricted				
Stonewort	*Nitellopsis obtusa*	**Starry Stonewort**	RDB:VU, BAP	4	2	
Fern	*Dryopteris cristata x carthusiana = D. x uliginosa*	Buckler fern	RDB:VU, S:NR	3	1	
Mollusc	*Anisus vorticulus*	**Little Ramshorn Whirlpool Snail**	RDB:VU, BAP	4	2	
Spider	*Carorita paludosa*	Money spider	RDB:VU	3	1	
Dragonfly	*Aeshna isosceles*	**Norfolk Hawker**	RDB:EN, BAP	5	1	
Dragonfly	*Coenagrion armatum*	**Norfolk Damselfly**	RDB:RE	5	1	1†
True bug (Hemiptera)	*Microvelia buenoi*	Broad-shouldered water strider	RDB:R	3A	1	
Beetle	*Agabus striolatus*	Predaceous diving beetle	RDB:VU	5	1	
Beetle	*Bagous diglyptus*	True weevil	RDB:EN	3	1	1†
Beetle	*Ceutorhynchus querceti*	True weevil	RDB:VU	3	1	
Beetle	*Graphoderus bilineatus*	Predaceous diving beetle	GRDB:VU, RDB:RE	4	2	1†
Beetle	*Meotica pallens*	Rove beetle	RDB:Insu	3	1	1
Moth	*Coleophora hydrolapathella*	**Water-dock Case-bearer**	BAP	3	1	
Moth	*Monochroa divisella*	**Scarce Marsh Neb**	RDB:VU	1	0	
True fly (Diptera)	*Dolichopus laticola*	**Broads Dolly-Fly**	RDB:EN, BAP	3	1	

True fly (Diptera)	*Neossos nidicola*	Heleomyzid fly	RDB:R	1	0	1
True fly (Diptera)	Sciomyza testacea	Snail killing fly		x	x	
Primary stronghold						
Stonewort	*Chara connivens*	**Convergent Stonewort**	RDB:EN, BAP	4	2	
Fern	*Dryopteris cristata*	**Crested Buckler-fern**	RDB:CR, S:NR, BAP	2	0	
Flowering plant	*Liparis loeselii*	**Fen Orchid**	RDB:EN, S:NR, BAP	3	1	
Flowering plant	*Peucedanum palustre*	**Milk-parsley**	RDB:VU, S:NS	3	1	
Flowering plant	*Sonchus palustris*	**Marsh Sow-thistle**	S:NS	3	2	
Flowering plant	*Stratiotes aloides*	**Water-soldier**	RDB:NT, S:NR	4	2	
Mollusc	*Oxyloma sarsii*	**Slender Amber Snail**	RDB:VU	3	2	
Mollusc	*Segmentina nitida*	**Shining Ramshorn**	RDB:EN, BAP	4	2	
Spider	*Clubiona juvenis*	Sac spider	RDB:VU	3	3	
Spider	*Dolomedes plantarius*	**Fen Raft Spider**	RDB:EN, BAP	4	1	
Crustacean	*Corophium lacustre*	Mud shrimp	RDB:R	4	3	
True bug (Hemiptera)	*Cosmotettix costalis*	Leafhopper	RDB:Insu	3	1	1
True bug (Hemiptera)	*Hydrometra gracilenta*	**Lesser Water Measurer**	RDB:R, BAP	4	1	
True bug (Hemiptera)	*Polymerus vulneratus*	Plant bug	RDB: EN	1	0	
Beetle	*Bidessus unistriatus*	**One-grooved Diving Beetle**	RDB:CR, BAP	5	2	
Beetle	*Cerapheles terminatus*	Soft-winged flower beetle	N:A	3	3	
Beetle	*Hydrochus megaphallus*	Water scavenger beetle	RDB:VU	4	1	
Beetle	*Lathrobium rufipenne*	Rove beetle	RDB:VU	3	1	
Beetle	*Lixus paraplecticus*	True weevil	RDB:EN	5	1	1†
Beetle	*Quedius balticus*	Large rove beetle	RDB:EN	3	1	
Beetle	*Stenus europaeus*	Water skater rove beetle	N:B	3	1	
Beetle	*Tapeinotus sellatus*	Fungus weevil	N:A	3	1	
Caddis fly	*Erotesis baltica*	Longhorned caddisfly	RDB:VU	4	1	
Moth	*Archanara algae*	**Rush Wainscot**	RDB:R	3	1	
Moth	*Chortodes brevilinea*	**Fenn's Wainscot**	RDB:R, BAP	2	0	
Moth	*Monochroa conspersella*	**Dingy Neb**	RDB:Inde	3	1	
Moth	*Pelosia muscerda*	**Dotted Footman**	RDB:R	3	1	
Moth	*Phragmataecia castaneae*	**Reed Leopard**	RDB:VU	3	1	
Moth	*Pseudopostega auritella*	**Fen Bent-wing**		3	1	
True fly (Diptera)	*Asindulum nigrum*	**Fen Flower Gnat**	RDB:NT, BAP	3	1	
True fly (Diptera)	*Phebellia nigripalpis*	Tachinid fly	RDB:VU	3	3	1
True fly (Diptera)	*Phytomyza thysselini*	Leaf-miner fly		3	1	1
Hymenoptera	*Odynerus simillimus*	**Fen Mason-wasp**	RDB:EN, BAP	6	1	
Hymenoptera	*Trigonalis hahnii*	Parasitic Wasp		3	1	
Bird	*Anser fabalis subsp. fabilis*	**Taiga Bean Goose**	B:R	3	2	

Note: This compilation of Broads Specialities is the most comprehensive and systematic undertaken to date, but further revisions may be required in response to new information. We invite further contributions from individuals with expert knowledge and hope that publication of this list may bring to light further Speciality species.

Distribution of the Broads Priority Species

Hotspots of priority biodiversity were confined to the Broads area compared to the wider area of 10-km squares across which records were collated and mapped, with the exception of several locations of regular moth traps (Figure 8).

Within the Broads, the distribution of priority species confirms the high importance of those remaining areas of peat fen particularly in the Ant, mid-Bure, Thurne and Mid-Yare (Figure 8 and Figure 9). Horsey Mere, Hickling Broad and areas of Winterton-Horsey Dunes were also hotspots for priority biodiversity with ≥180 priority species per km^2 in each of these areas. Considerable richness of priority species also occurred across the grazing marsh landscapes, particularly in the Waveney Valley (The Island, Belton Marshes, Fritton Marshes and Langely Marshes were all notable). Muck Fleet, Hardley Flood, Fritton Decoy and Lound Lakes were additional minor hotspots.

This contrasts with the distribution of Broads Speciality species, which were concentrated in the peat fens, especially those of the Rivers Ant and Bure (Figure 10), and is particularly evident when those Broad Specialities that are very well recorded, widely dispersing or sometimes introduced elsewhere are excluded (Common Crane *Grus grus,* Taiga Bean Goose *Anser fabalis subsp. fabalis,* Swallowtail *Papilio machaon,* Water Solider *Stratiotes aloides,* Norfolk Hawker *Aeshna isosceles*) (Figure 11).

Breydon Water contained significant numbers of priority species (Figure 9). However, birds comprised 68% of recorded species that were associated with estuarine or mudflat habitats. Biological recording of other species typical of estuaries was low in Breydon Water, following a national pattern. It is therefore expected that Breydon Water contains considerably greater biodiversity than currently known. The main area of grazing marsh at Halvergate is one of the few SSSI locations to have provided few priority species, but this must be assessed in view of the lack of recording in this area (Figure 5).


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There were records of ten Broads Speciality species outside of the core area of the Broads (Figure 8). These species were: Norfolk Hawker *Aeshna isosceles*, a diving beetle *Agabus striolatus* (Largely Restricted); Little Ramshorn Whirlpool Snail *Anisus vorticulus* (Largely Restricted); Fen Orchid *Liparis loeselii*[9] (Primary Stronghold); Swallowtail *Papilio machaon* (Entirely Restricted); Milk-parsley *Peucedanum palustre* (Primary Stronghold); Marsh Sow-thistle *Sonchus palustris* (Primary Stronghold); Water Solider *Stratiotes aloides* (Primary Stronghold); and two species recorded outside the Broads only before the cut-off date (<1989), Fenn's Wainscot *Chortodes brevilinea* (Primary Stronghold) and Shining Ramshorn *Segmentina nitida* (Primary Stronghold). Some of these species are highly mobile and therefore observations are less surprising or significant, e.g. Norfolk Hawker and Swallowtail, and others are likely to have been due to casual introductions e.g. Water Solider. Other more sedentary species with records outside of the Broads BAP include Little Ramshorn Whirlpool Snail, recorded to the north of Ditchingham, and Fen Orchid, recorded in the vicinity of Redgrave and Lopham Fens.

[9] Though this may be determined as a separate taxon to the broad-leaved variety occurring in Wales

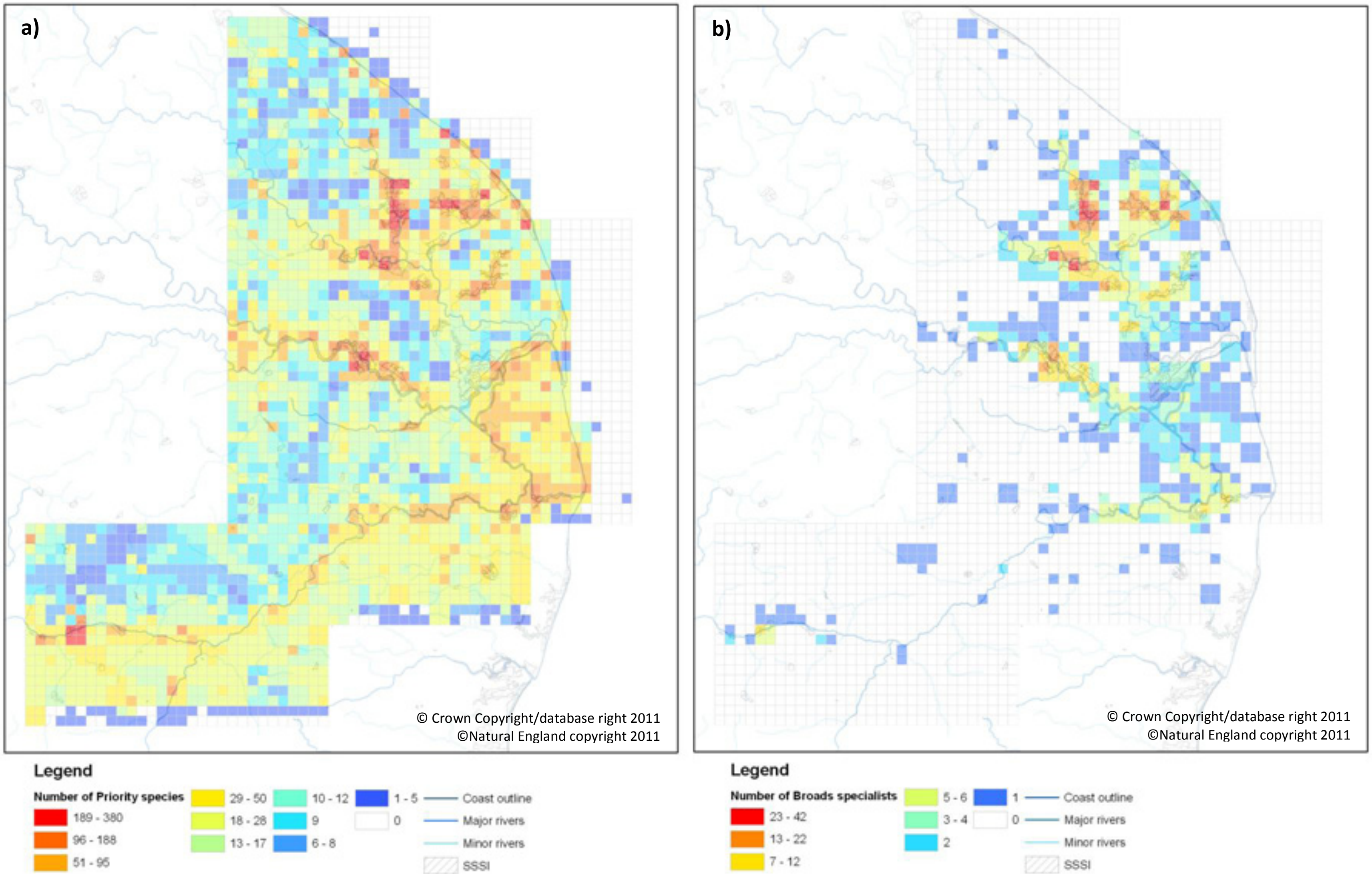

Figure 8. Distribution of a) Priority species b) Broads Specialities, records at 1km resolutions for the wider Broads region. Bands for categories defined by geometrical intervals. These maps are based on the 210,522 priority records, but using only 196,448 records which are at 1km or better resolution

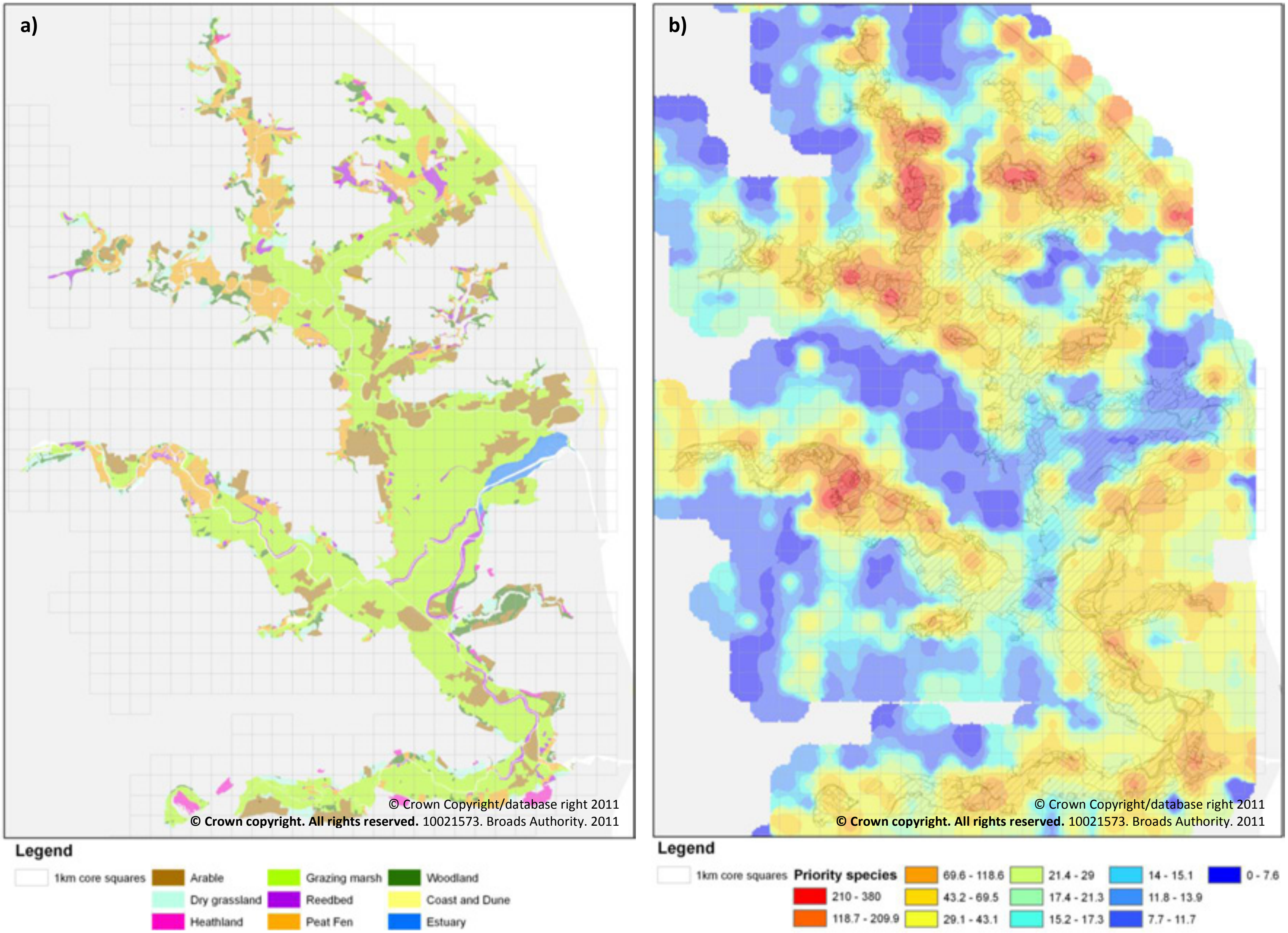

Figure 9. Distribution of a) habitat types, as classified by the Broads Authority, b) priority species, with habitats shaded for cross reference between maps

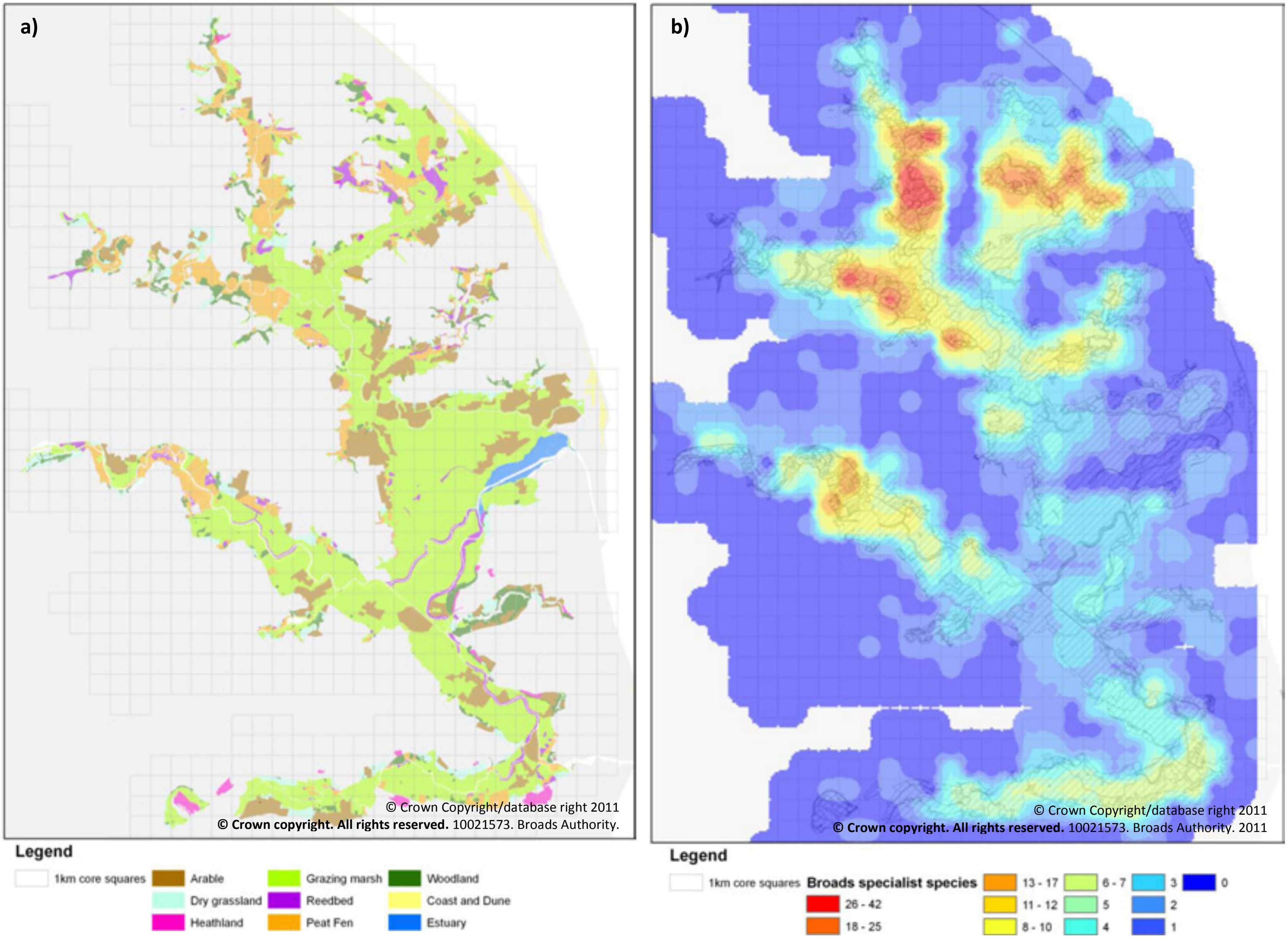

Figure 10. Distribution of a) habitat types as classified by the Broads Authority, b) Broads Speciality species within this same area, with habitats shaded for cross reference between maps

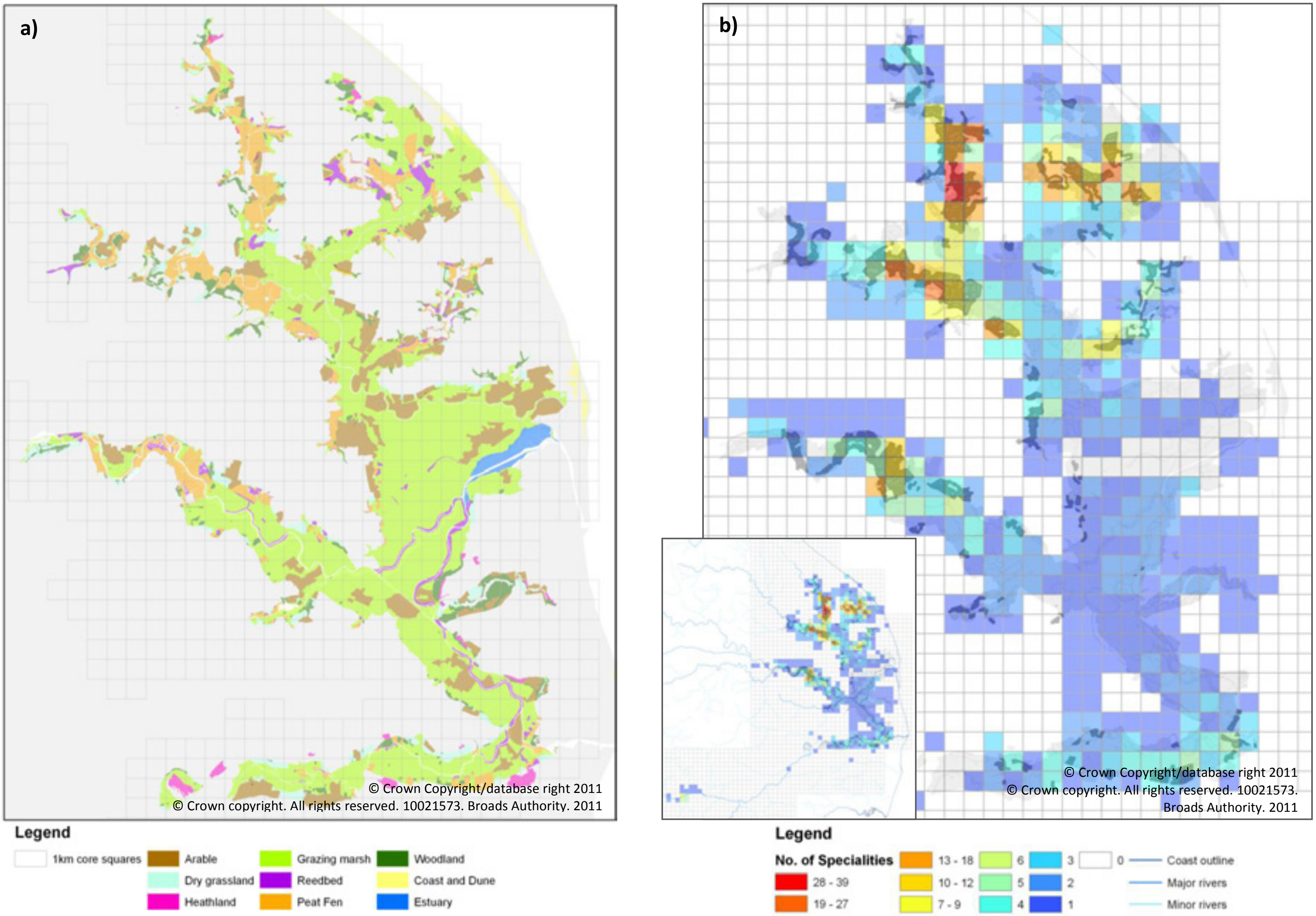

Figure 11. Distribution of a) habitat types, as classified by the Broads Authority, b) Broads Speciality species as in Figure 8 above, but excluding more widely dispersed Speciality species (Common Crane, Taiga Bean Goose, Swallowtail, Water Solider, Norfolk Hawker), showing the same habitat layers as the map left (light grey) and with peat fen areas highlighted (dark grey)

Habitat associations of the Broads Priority Species

Sufficient literature was available regarding habitat preferences and associations to enable virtually all (98%) of the 1519 priority species occurring in the Broads to be classified. Almost half of the 22 species that could not be classified were Diptera, for which habitat preferences are often unclear. Others include parasitic species and whilst the host is known for most, their distribution and ecology is based on scattered observations and is often unclear.

Only 22% (330 species) of the priority taxa coded were classified as being primarily associated with a single broad habitat type. Most species were not assigned to a single primary habitat (mean ± SD 2.5 ± 1.2 habitats). Considering both primary and secondary habitat associations, priority species were assigned to 4.4 ± 2.1 (SD) habitats with a maximum of 18 habitats for an individual priority species, the Common Toad *Bufo bufo* (BAP).

In interpreting these results, it is important to bear in mind that:

- The analysis considers associations from the literature, so may include associations with habitats not present or prevalent the Broads
- Since species were classified with more than one primary habitat association, the total number of habitat associations is greater than the number of priority species

Key habitats for Biodiversity

The relative importance of different habitats to the priority biodiversity was quantified, in terms of the numbers of species that have a primary association with each habitat. Results are shown in Figure 12 and can be summarised as:

Fen >> Wet Grassland > Dry Grassland > Wood Pasture > Woodland > Small Standing Waterbodies ≈ Heathland > Littoral and Lake margins ≈ Coastal ≈ Sand Dune >> Brownfield ≈ Arable ≈ Reedbed

>> many more species associated with; > more species associated with; ≈ approximately equal numbers of species associated with

Unsurprisingly, this confirms the very high importance of fen habitats, which support the primary habitat association of 246 priority species (Figure 12) and is the sole primary habitat of 25 species (Table 6). Wet grassland was the next most important habitat, with 203 priority species.

A greater number of species were primarily associated with smaller standing waterbodies (pools, ponds and wet hollows) than with larger standing waterbodies (lakes and broads), 133 and 78 primary associations respectively. However, larger standing waterbodies were the sole primary habitat for 11 species, compared to only four in small waterbodies (Table 6).

Relatively few priority species had primary associations with fen carr and wet woodland, 62 and 59 species respectively. The importance of closed, shaded wetland to priority biodiversity was, therefore, found to be lower than that of open wetland habitats (e.g. fen, reedbed, wet grassland, standing waterbodies). However, this may to some extent be influenced by low sampling effort in fen carr and wet woodlands (M. Horlock pers comm.) and the Broads Authority have commissioned invertebrate surveys of wet woodland in 2011 to increase knowledge of these habitats. Fen meadow appeared to support low numbers of priority species, but this is likely to reflect the lack of distinction in the literature used to classify species between broader ‘fen’ and more specific ‘fen meadow’.

Fen
© Broads Authority

Weevil *Tapinotus sellatus*
© Christoph Benisch

Fen is the most biodiverse habitat in the Broads. It supports a wide range of priority species and Broads Specialities, such as the weevil *Tapinotus sellatus* (Notable A, primary stronghold). It is associated with Yellow Loosestrife *Lysimachia vulgaris.*

The importance of coastal habitats to biodiversity in the Broads was also confirmed, with sand dune being particularly important (Figure 12). Relatively low numbers of priority species were associated with brackish waterbodies (as distinct from brackish conditions or habitats more generally), with only 36 primary associations.

Arable landscapes are important dry habitats
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One very striking result was the biodiversity importance of dry habitats within the Broads (Figure 12), particularly dry grasslands, lowland heathland, arable, and woodlands. Although these habitats are now relatively scarce in the landscape of the Broads, large numbers of recorded priority species were associated with them. The biodiversity importance of heathland should particularly be considered in contrast to the very small area remaining (Figure 9a). Although much of the heathland area was lost during enclosure in the late 18th and early 19th centuries (Williams 1997), some additional areas probably remained until the 1930s (Shardlow 2007), and many priority species associated with these habitats still remain. Conservation strategy should therefore, consider the wider landscape and its quality, in addition to the important focus on the wetland resource.

Many priority species (159) were classified as having a primary association with wood pasture. There is little true wood pasture in the Broads landscape, but there are areas of open woodland, parkland and woodland edge that provide mature trees in an open, usually grassland context. During the classification of species habitat associations, open woodland, parkland and open woodland edge species were assigned to the wood pasture category. Both woodland and wood pasture was very important for biodiversity (Figure 12). However, of those 159 species classified as having primary associations with wood pasture, 62% also had primary associations with woodland; likely due to the similarity in microhabitats, e.g. veteran trees and deadwood.

The ranking of habitat associations was similar when considering just those species that are restricted to a single broad habitat type; the largest numbers were associated with fen (25 species), reed bed and reed swamp (22 species) and dry grassland (16 species) (Table 6).

Key habitats for Broads Speciality species

The relative importance of different habitats to those priority species identified as Broads Specialities (entirely, largely, or primarily restricted to the Broads within the UK) can be summarised as:

> Fen >> Wet Grassland > Small Standing Waterbodies ≈ Reedbed and Reed Swamp ≈ Ditches and Dykes
>
> >> many more species associated with; > more species associated with; ≈ approximately equal numbers of species associated with

Unsurprisingly, all Broads Speciality species were primarily associated with wetland habitats, with the largest associated with fen (Table 6). One Broads Speciality species, *Neossos nidicola* (Heleomyzid fly), was associated both with fen and a terrestrial habitat, wood pasture. This emphasises the importance of considering the heterogeneity and juxtaposition of habitats within the wider landscape and not solely focusing on the wetland elements.

Fen Biodiversity: pools and mossy seepages


How Hill turf pond
© Broads Authority

Fen pools and seepages support important assemblages of invertebrates, including many water beetles. The minute moss beetle *Hydraena palustris* (RDB:NT) is one the important species of the East Anglia-Lincolnshire fen water beetle complex, which is associated with the richest and most natural fen (Foster & Eyre, 1992). *Hydraena palustris* occurs in mossy swamps in eutrophic or mesotrophic fens, preferring temporary or semi-permanent stagnant water; Balfour-Brown collected many in the Broads by stamping on moss in submerged clear water (Balfour-Browne 1940, 1950, 1958). Although more widespread in Europe, populations of *Hydraena palustris* in Britain are isolated and occur at low densities. Minute moss beetles, despite being 'aquatic' as adults, possess limited swimming ability and the larvae are prone to drowning. The predacious Mr. Scales' diving beetle *Hydroporus scalesianus* (RDB:VU) is primarily found in relict fen and fen carr, but can also be found in woodland pools. It is typical of swampy marsh with floating vegetation mats or areas of thick water-logged moss with occasional tussocks; clear, shallow water is also essential (Foster, 2010; Balfour-Browne 1940, 1950, 1958). These conditions are also provided by areas of reed cutting and the species appears to do well in these areas (Foster, pers. comm). The conservation of Mr. Scales' diving beetle at relict fen sites is extremely important because, in Britain, the species appears unable to colonise new sites unaided (Foster, 2010).

Habitat associations for each taxonomic group

The relative abundance of priority species from different taxonomic groups varied considerably among habitat types (Figure 13). The priority biodiversity of large standing waterbodies was dominated by vertebrates, mostly birds. In contrast, fen carr and scrub were dominated by priority true flies (Diptera) and fen by true flies (Diptera) and beetles (Coleoptera). The arable landscape contained large numbers of priority vascular plants.

Table 6. Habitat associations of the 1096 priority species recorded in the Broads since 1988, excluding species for which habitat information was not available and vagrant birds

Habitat category	No. of associations as Secondary Habitat	No. of associations as Primary Habitat	No. of species with unique association with habitat	No. of Broads Speciality species with Primary association	Habitat category	No. of associations as Secondary Habitat	No. of associations as Primary Habitat	No. of species with unique association with habitat	No. of Broads Speciality species with Primary association
Running water	110	46	1	0	Sand dune	54	112	12	0
Standing Water - Small	100	133	4	9	Wet Grassland	236	203	13	10
Standing Water - Large	111	78	11	5	Dry grassland	145	185	16	0
Brackish waterbodies	24	36	2	1	Lowland Heath	61	125	7	0
Fluctuating waterbodies	21	15	0	0	Arable & horticulture	63	84	11	0
Ditches/dykes	61	75	2	8	Brown-field	67	89	15	0
Fen meadow	110	35	1	7	Gardens	5	1	0	0
Fen	159	246	25	22	Isolated riverine trees	10	5	0	0
Reed bed and reed swamp	85	85	22	9	Fen carr and scrub	45	62	11	3
Bog and mire	48	65	7	1	Wet woodland	43	59	2	1
Littoral/Lake margins	73	116	8	6	Scrub	37	63	0	0
Poaching	5	3	0	0	Hedgerow	29	67	0	0
Clear water	9	7	0	1	Wood pasture	58	159	5	1
Aquatic vegetation	18	18	0	2	Woodland	77	143	13	0
Marine	16	21	0	0	Veteran trees	13	5	0	0
Estuary/mudflat	30	25	0	0	Deadwood	18	19	2	0
Coastal habitats	108	113	9	0	Detritus/ Detritivore	38	24	12	1
Saltmarsh	37	58	5	1	Sandpits, Gravelpits, Chalkpits	54	55	1	0
Coastal shingle	22	35	0	1	Walls/Concrete features	21	19	12	0

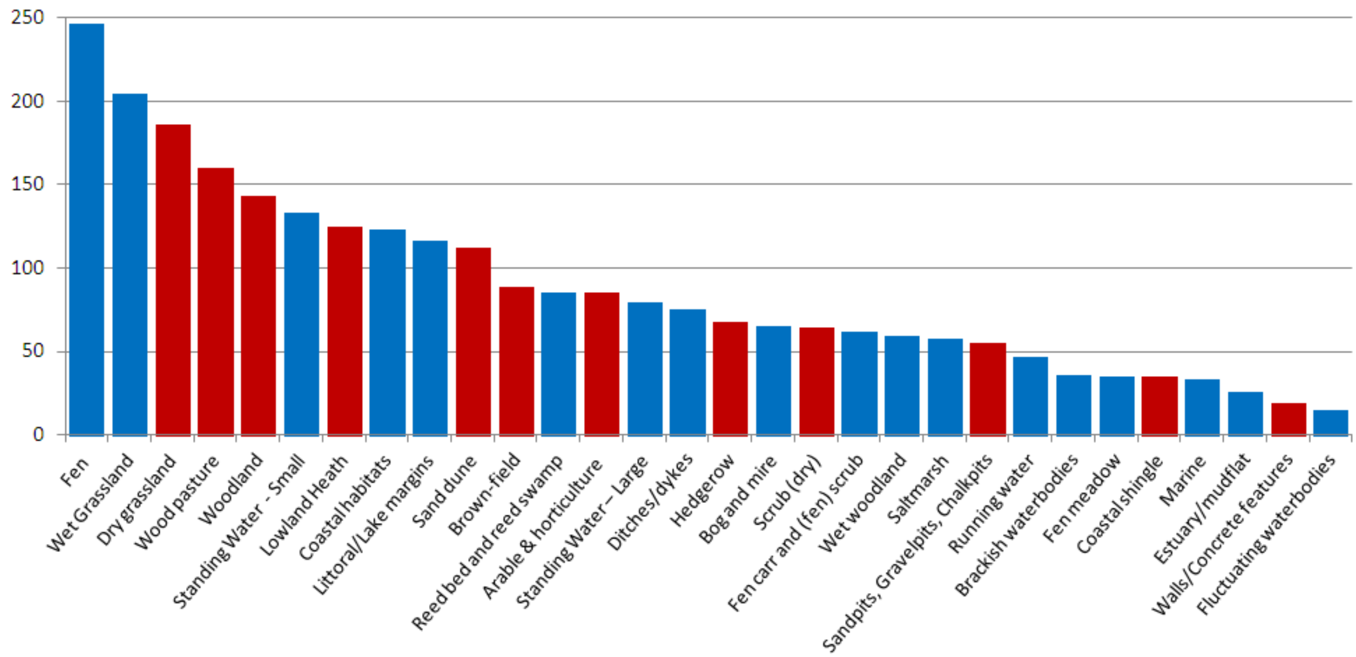


Figure 12. The relative importance of habitats defined by the number of associations with priority species in the Broads, i.e. the number of species classified from the literature as having a primary association with the habitat. Note: not all of these habitats are well represented within the Broads landscape and individual species may be primarily associated with more than one habitat, so that the total number of primary habitat associations (2,689) is much greater than the total number of priority species (1,051)

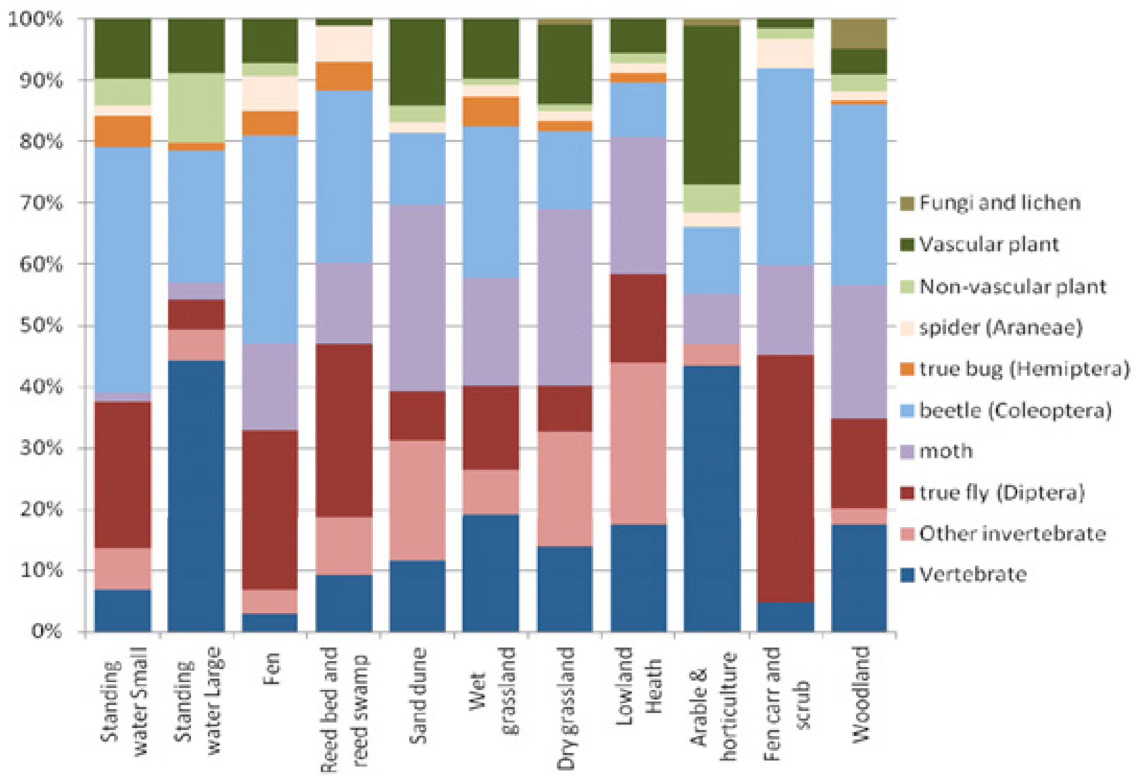


Figure 13. Cumulative percentage of the number of primary associations from different taxonomic groups with selected habitat types. N = the number of primary associations within each habitat type (Table 6)

Extinctions in the Broads

No modern records (post-1988) were obtained for 28% (423 species) of the total number of priority species (1,519 species) recorded in the Broads. A far greater proportion of the species not recorded since 1988 are associated with dry or damp habitats compared to wet habitats than is the case for species recorded since 1988 (χ^2_1 = 30.4, p=0.001; pre-1988 only: 2.1:1, comprising 277 dry/damp versus 134 wet taxa; post-1988 records: 1.2:1, comprising 542 dry/damp versus 511 wet taxa). This may indicate a loss of landscape heterogeneity within the Broads, particularly the loss of dry acidic grassland, heath and heathland-ecotones as well as a reduction in the biodiversity value of arable landscapes.

Of the 423 species with no recent records, 67 were acknowledged as extinct or locally extirpated (Table 8), including six Broads Speciality species. Forty-six percent of species acknowledged as extinct or extirpated were last recorded prior to 1940 and a further 44% of species were last recorded between 1940 and 1980.

The 67 extirpated species include two vertebrates, 23 flowering plant species and 10 Lepidoptera. The majority (51%) of the historic species for which there was understanding of their ecology were associated with dry habitats and were previously recorded throughout the wider Broads area (Figure 14). Large numbers of historic species were associated with dry terrestrial rather than wetland habitats, e.g. 17 species were primarily associated with dry grassland.

Apparent losses of species associated with wetland and fen habitats are of particular concern in the context of the Broads region. Extirpated species included 13 species associated with fen, 11 species with wet grassland and a further 11 species with littoral/lake margins. These species were from a wide range of taxonomic groups, including many reed beetles (*Donacia* spp.). Reed beetles are associated with the littoral edge and large emergents of small standing waterbodies, and are thought to have suffered from a loss and deterioration of the quality of these habitats in the Broads. They would however, be expected to still occur in well-vegetated ditches (Hyman and Parsons 1992, G. Foster pers. comm.). Other notable species include the Norfolk Damselfly *Coenagrion armatum*, which bred in ponds and ditches with aquatic vegetation for ovisposition and was formerly entirely restricted to the Broads within the UK. The Great Yellow Bumblebee, *Bombus distinguendus* was widely recorded throughout the British Isles, often in wetlands, including Ranworth Broad, but is now a flagship for the decline of bumblebees and is restricted to moorland and machair in northern and western Scotland.

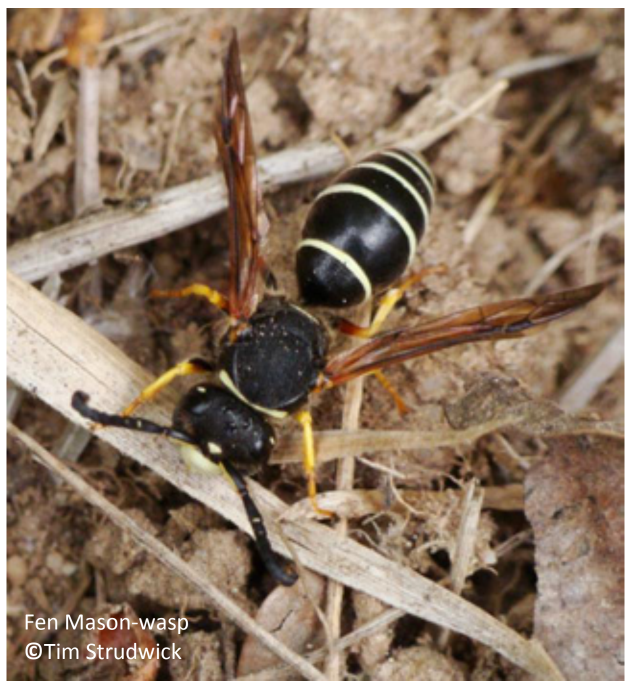
Salinity tolerance was coded for 26 of the 67 extirpated species; 40 species were associated with dry or damp habitats and were not coded, and insufficient information was available to code for the remaining one species. The majority of extirpated species coded for salinity tolerance were freshwater species (81%), intolerant of saline conditions. Only one species, was tolerant of highly saline conditions (category 4), the Common Sturgeon *Acipenser sturio* that would once have migrated from the sea up-stream into fully freshwater habitats. One extirpated species, a water beetle *Helophorus alternans*, was tolerant of mildly to moderately brackish (category 3) conditions and three species were tolerant of slightly brackish conditions or occur as a stray in brackish conditions (category 2), the water beetle *Graphoderus bilineatus*, Burbot *Lota lota* and Bird's nest stonewort *Tolypella nidifica*. Among the 26 species for which no recent records were found, a greater proportion were intolerant of even slightly brackish conditions 81 % (chi-square = 3.45, p= 0.063) (Table 9), compared to those with recent records. Of the recently recorded species (post-1988, 511 species), 63 % are intolerant of even slightly brackish conditions. This is compatible with saline intrusion leading to some species loss; however although the

River Ant valley is a hotspot of extirpated freshwater species (Figure 14), this is likely to be related to habitat loss or water pollution rather than saline incursion.

The status of the remaining 356 species for which the Audit has no records since 1988, is largely unknown. These species may now be extirpated or may remain in the region but have not been recorded or records were not received by the Biodiversity Audit. In order to establish the status of these species, further biological recording is required, through discussion of individual species with local recorders and national societies, and targeted recording at the last known sites. However, before this is conducted, there is a need to assess the list to prioritise important wetland species and remove less relevant species, such as ephemeral, arable plant species that have undergone national declines.

Recent records were received for a number of species considered to be nationally extinct (e.g. by the NE 'Lost Life Report') (Table 8). This can occur because species listed as extinct in RDBs and the Lost Life publication refer to native breeding populations, whereas modern records in the Audit database may refer to infrequent vagrant or migrant individuals. Furthermore, recent records may be received for introduced individuals of species with extinct native populations, and some recent records may be as a result of mis-identifications. However, it is likely that some recent records of apparently extinct species are genuine, demonstrating that proving extinction is always more difficult than showing that a species still persists!

The Fen Mason-wasp *Odynerus simillimus* was formerly regarded as extinct in Britain, but was rediscovered in the Norfolk Broads in 1986. Fen Mason-wasp nests on a range of substrates with areas of bare, exposed material, often those raised as a result of human activity, such as flood banking, spoil from ditch excavation and raised tracks (Strudwick, 2008). The species utilises reedbed, fen or other wetland for foraging of nectar sources and prey. It stocks its nests with weevil larvae (Lee & Scott, 2007) and other wetland invertebrates (Falk, 1991). This species is coded as flooding tolerance 6, since it requires both wet and dry habitats. The fen mason-wasp and *Crabro scutellatus*, a less rare hymenoptera that also nest in dry habitats but predates wetland flies, possibly represent a larger community of biodiversity that require such conditions.



Fen Mason-wasp
©Tim Strudwick

Table 7. Hydrological and salinity tolerances and vulnerabilities of priority species not recorded in the Broads since 1988

Taxonomic group	No. of priority species	No. of species uncoded for tolerance	Hydrological tolerance categories						Salinity tolerance categories			
			1 (dry terrestrial)	2 (damp)	3 (wet)	3A (Littoral)	4 (fully aquatic)	5 (part-aquatic)	1 (freshwater)	2 (slight saline influence)	3 (brackish -moderate)	4 (fully saline)
Fungi and lichen	24	4	15	1	4	0	0	0	4	0	0	0
Vascular plant	57	4	35	11	5	2	0	0	5	1	1	0
Non-vascular plant	14	0	3	2	4	1	4	0	8	1	0	0
Spider	8	0	4	2	2	0	0	0	2	0	0	0
True bug (Hemiptera)	13	0	7	2	3	0	1	0	3	0	1	0
Beetle	157	1	87	10	20	13	15	11	50	2	5	2
Moth	35	0	25	7	3	0	0	0	3	0	0	0
True fly (Diptera)	78	3	36	12	19	4	0	4	18	1	6	2
Hymenopteran	11	0	10	0	1	0	0	0	1	0	0	0
Other invertebrate	21	0	7	0	1	0	11	2	12	0	1	1
Fish	4	0	0	0	0	0	4	0	0	2	0	2
Terrestrial mammal	1	0	1	0	0	0	0	0	0	0	0	0
Total	423	12	230	47	62	20	35	17	106	7	14	7

Table 8. Priority species considered to be extinct in the UK or locally extirpated in the Broads region, organised by those recognised in the Natural England Lost Life publications (Brown et al. 2010), those designated as Red Data Book: Extinct and those identified as extirpated during the Broads Biodiversity Audit. U represents unknown dates. Asterisk indicates species previously only recorded outside of the Broads BAP area. Broads Speciality status is also shown; Entirely Restricted (ER) to the Broads, Largely Restricted (LR), Primary Stronghold in the region (PS)

Taxon group	Taxa Latin Name	Designation	Broads Speciality	Most recent record from database (Last date from Lost Life)
		Lost life		
Flowering plant	*Carex trinervis*	RDB:EX	ER	1869 (1869)
Flowering plant	*Galeopsis segetum*	RDB:EX		1862 (1980s)
Flowering plant	*Tephroseris palustris*	RDB:EX		1928 (1947)
Beetle	*Meligethes coracinus*	RDB:EX		<1975 (1870s)
Moth	*Aristotelia subdecurtella*	RDB:EX		1874 (C19th)
Moth	*Eremobina pabulatricula*	RDB:EX		1961
Moth	*Lymantria dispar*	RDB:EX		2004 (1907)
		Red Data Book: Extinct		
Fungus	*Puccinia asparagi*	RDB:EX		1935 (1936)
Fungus	*Puccinia cicutae*	RDB:EX		1940 (1958)
Fungus	*Puccinia cladii*	RDB:EX		1958 (1957)
Stonewort	*Tolypella nidifica*	RDB:EN, BAP		U (1956)
Flowering plant	*Bupleurum rotundifolium*	RDB:CR, S:NR, BAP		1987 (1970)
Flowering plant	*Chenopodium urbicum*	RDB:CR, S:NR, BAP		1950 (U)
Odonata	*Coenagrion armatum*	RDB:RE	LR	1953 (1958)
Beetle	*Bagous diglyptus*	RDB:EN	LR	<1965 (1897)
Beetle	*Graphoderus bilineatus*	GRDB:VU, RDB:RE	LR	1906 (1906)
Beetle	*Lixus paraplecticus*	RDB:EN	PS	1899 (1958)
Beetle	*Spercheus emarginatus*	RDB:RE		1956 (1956)
Butterfly	*Aporia crataegi*	RDB:RE		1913 (1920s)
Butterfly	*Lycaena dispar*	GRDB:NT, RDB:RE		1949 (1864)
Moth	*Hadena irregularis*	RDB:EN		1899 (1968)
Moth	*Pyrausta sanguinalis*	RDB:EN, BAP		1938 (1935)
Hymenoptera	*Bombus distinguendus*	N:B, BAP		1937 (1981)
Fish	*Lota lota*	BAP		1972 (1969)
		Additional extirpated species recognised by the Audit methodology		
Lichen	*Caloplaca luteoalba*	RDB:VU, S:NS, BAP		1977
Clubmoss	*Lycopodiella inundata*	RDB:EN, S:NS, BAP		1951
Flowering plant	*Aceras anthropophorum*	RDB:EN, S:NS, BAP		1894
Flowering plant	*Adonis annua**	RDB:EN, S:NS, BAP		1987
Flowering plant	*Centaurea calcitrapa*	RDB:CR, S:NR, BAP		U
Flowering plant	*Chamaemelum nobile*	RDB:VU, BAP		1894
Flowering plant	*Chenopodium vulvaria*	RDB:EN, S:NS, BAP		1987
Flowering plant	*Clinopodium calamintha*	RDB:VU, S:NS		1950

Flowering plant	*Deschampsia setacea*	S:NS		1961
Flowering plant	*Euphrasia pseudokerneri*	RDB:EN, S:NS, BAP		1950
Flowering plant	*Filago pyramidata*	RDB:EN, S:NS, BAP		1950
Flowering plant	*Galium tricornutum*	RDB:CR, S:NR, BAP		1955
Flowering plant	*Gastridium ventricosum*	S:NS		U
Flowering plant	*Herminium monorchis**	RDB:VU, S:NS, BAP		1936
Flowering plant	*Lolium temulentum*	RDB:CR, S:NR, BAP		1973
Flowering plant	*Lythrum hyssopifolia*	RDB:EN, S:NR, BAP		1981
Flowering plant	*Ophrys insectifera*	RDB:VU, BAP		1894
Flowering plant	*Pulicaria vulgaris*	RDB:CR, S:NR, BAP		1950
Flowering plant	*Teucrium scordium*	RDB:EN, S:NR, BAP		U
Flowering plant	*Valerianella rimosa**	RDB:EN, S:NS, BAP		1987
Mollusc	*Myxas glutinosa*	GRDB:DD, RDB:EN, BAP		1968
Orthoptera	*Stethophyma grossum*	RDB:VU, BAP		1939
Hemiptera	*Polymerus vulneratus*	RDB:EN	PS	1954
Beetle	*Anostirus castaneus*	RDB:EN, BAP		1936
Beetle	*Cicindela hybrida*	RDB:VU, BAP		1968
Beetle	*Donacia bicolora*	RDB:VU, BAP		1918
Beetle	*Donacia cinerea*	N:B		1965
Beetle	*Donacia crassipes*	N:B		1965
Beetle	*Donacia obscura*	N:A		1906
Beetle	*Donacia sparganii*	N:A		1902
Beetle	*Enicocerus exsculptus*	S:NS		<1900
Beetle	*Gnorimus nobilis*	RDB:VU, BAP		1894
Beetle	*Gyrinus minutus*	S:NS		1904
Beetle	*Helophorus alternans*	S:NS		<1950
Beetle	*Pterostichus aterrimus*	RDB:EN		1910
Beetle	*Rhantus bistriatus*	RDB:EN		1906
Butterfly	*Boloria euphrosyne*	RDB:EN, BAP		1977
Moth	*Agonopterix atomella*	BAP		1936
Moth	*Athrips tetrapunctella*	RDB:INDE		1884
Hymenoptera	*Ancistrocerus antilope*	RDB:R		1939
Hymenoptera	*Anthophora retusa*	RDB:EN, BAP		1930
Hymenoptera	*Bombus sylvarum*	N:B, BAP		1957
Fish	*Acipenser sturio*	GRDB:CR, BAP		1972

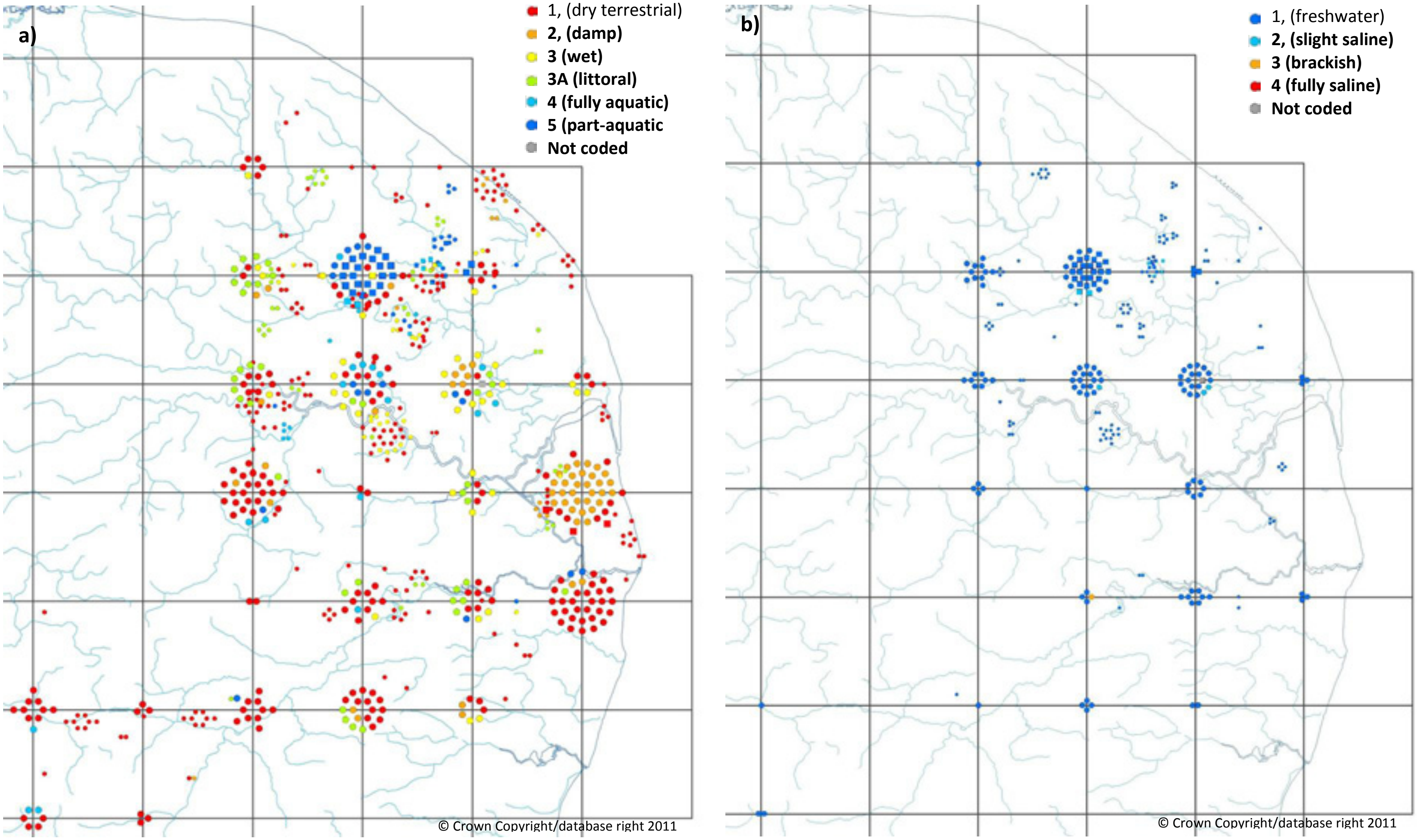


Figure 14. Location of records of Broads Speciality species (squares) and other priority species (circles) known or considered to be nationally extinct or regionally extirpated. Large points represent 10 km observations and small points represent four-figure or greater grid references. Markers at the same grid reference are dispersed in rings surrounding the central point. Figure 14a shows hydrological tolerance/vulnerability categories. Figure 14b shows salinity tolerances.

Salinity mapping

River Salinity

Environment Agency river monitoring data showed that, between 1990 – 2010, chloride concentrations in the upper reaches of the River Bure (Horsted Mill), River Yare (Trowse Mill) and River Ant (Honing Lock) were less than 120 mg/l (except one record of 181 mg/l in August 1998 at Horstead Mill) and relatively stable (Figure 15). Although the Mid-Yare (Buckenham Ferry) showed a low frequency of saline events, chloride concentrations during one event in November 2006 reached 2400 mg/l – saline tolerance category 3. Sampling stations at Irstead Church (Ant) and Catfield Pump (Thurne) showed moderate conductivity with infrequent saline events. The highest salinity, consistently tolerance category 3, was recorded in the vicinity of Horsey at the Brograve Pump with salt water being drawn through from the North Sea via the Crag aquifer.

Grazing Marsh Salinity

Most of the sampled ditch network within the grazing marshes provided conductivity measures that exceeded the Venice System definition of freshwater, with extensive areas of mildly to moderately brackish ditch networks in the lower Waveney, lower Yare, the Halvergate-Acle Marshes and the Thurne, with localised areas of higher salinity (Figure 16). However, as discussed on page 23, the relationship between conductivity and salinity is complex at low saline concentrations. Furthermore, the hydrology of the grazing marsh system is highly complex, with springs and upwellings of freshwater (see variation in salinity in Halvergate Marshes, Figure 16). Site-specific contour mapping of salinity is needed in order to fully understand this complexity. Very highly saline conditions (>25,800 µS) were rarely recorded in grazing marsh, with isolated locations in grazing marsh surrounding Breydon Water and dykes in the upper Thurne.

Unfortunately, there was little geographic overlap in the available grazing marsh conductivity data for the differing time periods. However, at locations where overlap did exist, there appears to be no obvious increase in salinity over the time periods (Figure 16). It is recommended that the existence of further conductivity data sets are explored and detailed site-based comparisons through time are made. It is further recommended that a series of regular monitoring stations are established, within grazing marsh complexes that may be subject to differing changes in salinity and/or hydrology.

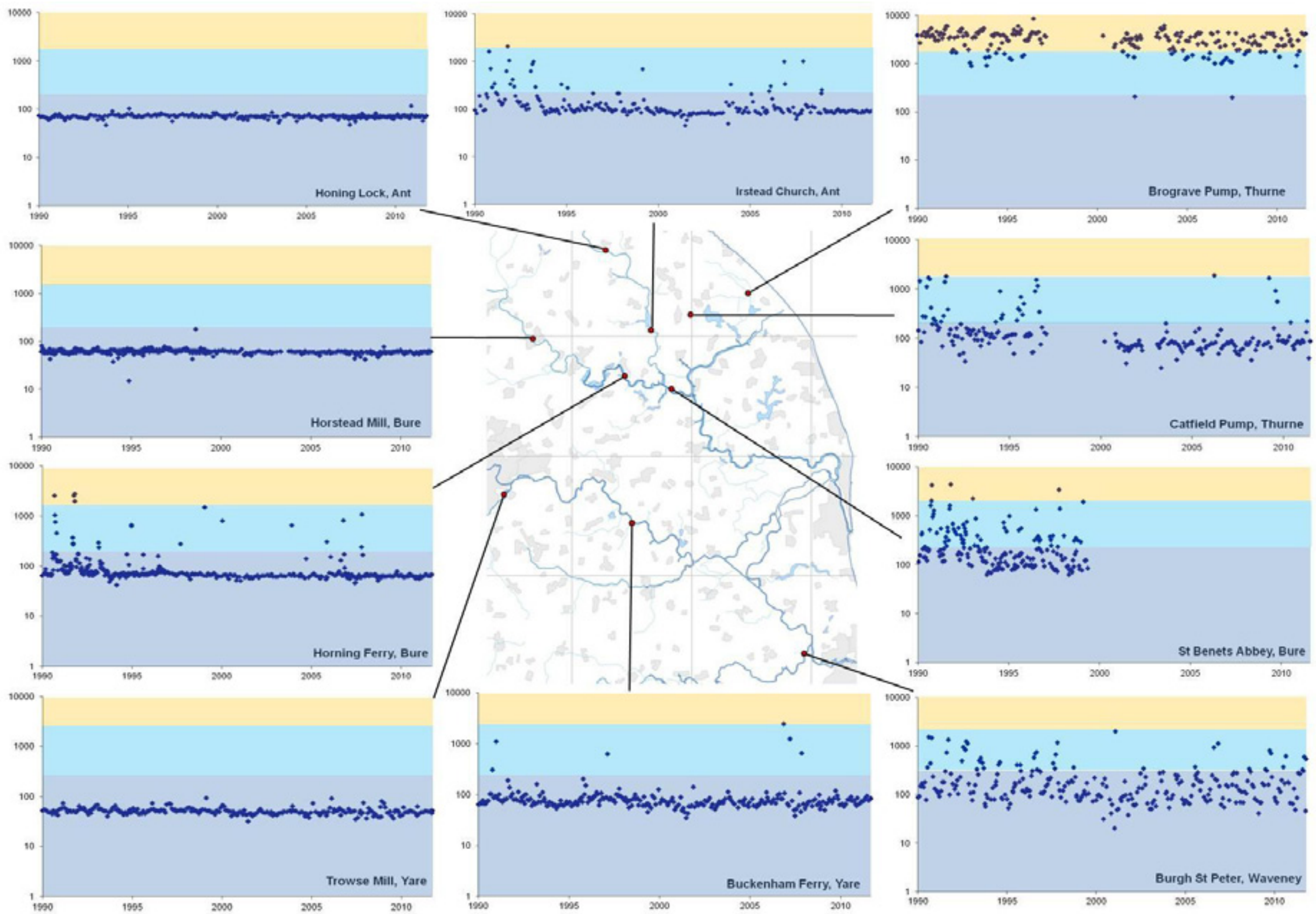


Figure 15. The location of Environment Agency river sampling stations and chloride concentrations (mg/l) recorded at each station between January 1990 and August 2011. Corresponding salinity tolerance/vulnerability categories (categories 1-3) used in the Biodiversity Audit are shown

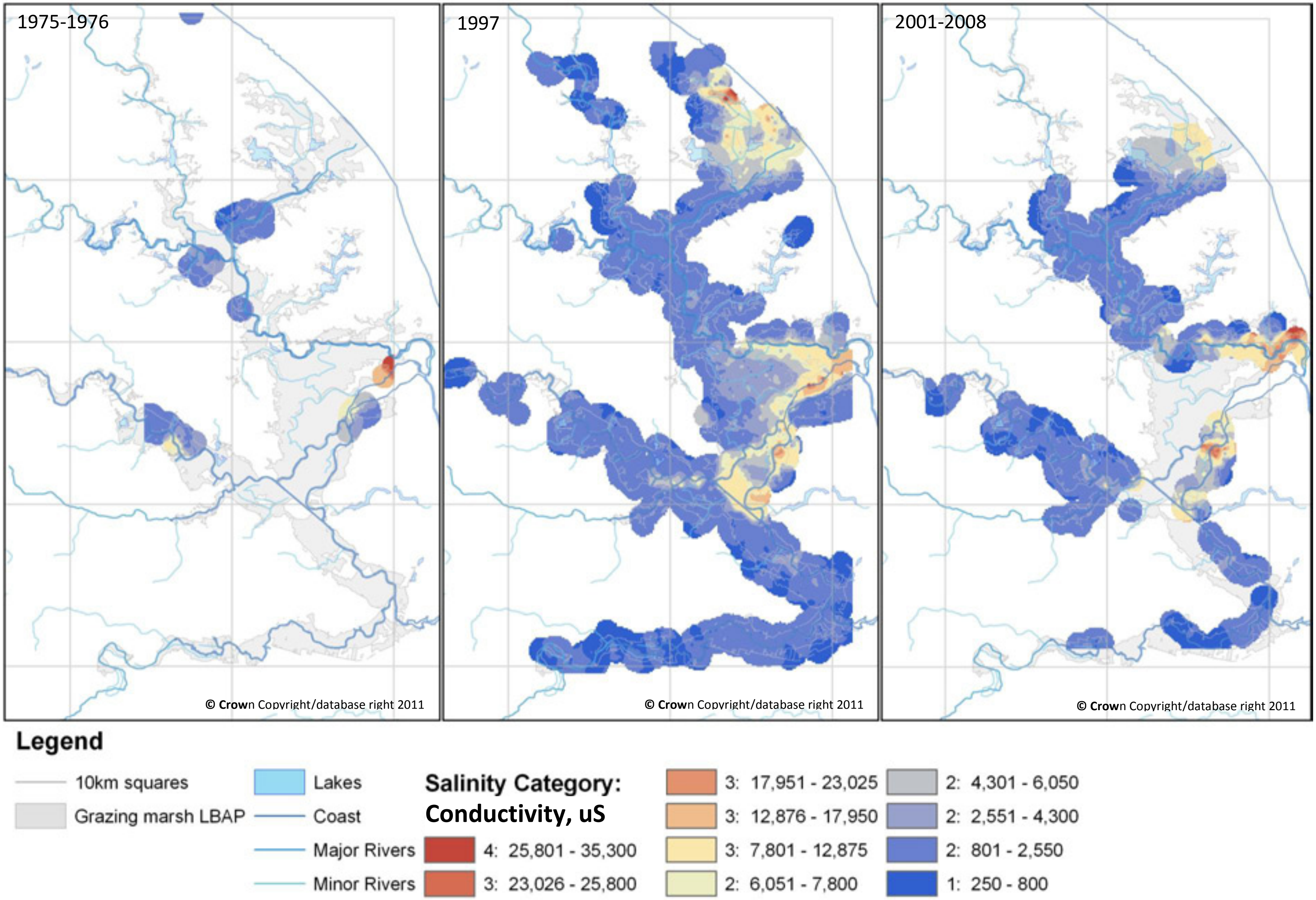


Figure 16. Spatial variation in conductivity measures from grazing marsh dykes (smoothed by inverse distance weighting, and only showing areas within 750m of sample points), shown separately for three time periods: 1975-1976 (Driscoll, unpublished), 1997 (NE data), 2001-2008 (BESL and BA data)

Salinity and Hydrology Tolerances of Broads Biodiversity

Of the 1,096 priority species recorded in the Broads since 1988, 1,053 (96%) were successfully coded for hydrological and salinity tolerance. Tolerances were not coded for gull species and could not be coded for a further 29 other species for which the available information was insufficient. Often broad habitat association(s) comprised the only known information for these species.

Hydrological Tolerance and Vulnerability

Fifty-two percent of the priority species in the Broads have a very high vulnerability to increased water levels and a variable, but generally higher, tolerance to drought (category 1 and 2 species) (Table 9, Table 10). However, these include only three Broads Speciality species. Most (59%) Broads Specialities are associated with wet habitats (category 3 species), with a high vulnerability to droughting and some vulnerability to flooding. Fully aquatic species with the highest vulnerability to droughting (category 4), only comprise 10% priority species but 25% of Broads Specialities.

Species responses to hydrological change are complex and often contradictory. For example, the Narrow-mouthed Whorl Snail *Vertigo angustior* in Broadland (listed hydrological tolerance category 2) typically occurs in moist open habitats such as damp or wet grassland or in marshes, including salt marshes (BAP plan). However, it is restricted to sites with a stable hydrology, i.e. sites that are neither affected by periodic desiccation or flooding. The current distributions of this species may represent locations where the hydrological balance has historically remained stable (Kerney 1999). However, dispersal within, and between sites, may be dependent on an increase in water level and hydrological connectivity, such as that caused by periodic flooding. This may be particularly important to colonisation of new habitat by isolated populations of flooding tolerant but low-dispersal ability species, such as snails (Jackson & Howlett 1999).

The mining bee *Macropis europaea* (Notable A) (hydrological tolerance category 3) is relatively widespread in East Anglian wetlands where Yellow Loosestrife *Lysimachia vulgaris* is abundant (Lee et al., 2008). *Macropis europaea* excavates nests, which may be concealed by overhanging vegetation, in banks and slopes that are above the maximum summer water level. However, it has been suggested that it may have some adaptions to flooding risk. Its nests have been found to contain a wax-like waterproof substance lining the cells, which is thought to be derived from the floral oils of *Lysimachia* sp. This lining is thought to ensure suitable humidity and may also prevent water seeping into the nest, especially during winter, when periodic flooding may be a common risk (Falk 1991a).

Macropis europaea
©Jeremy Early

Salinity Tolerance and Vulnerability

Sixty-three percent of priority species require fully freshwater conditions and are considered to be unlikely to tolerate brackish influence (Table 9). Thirteen percent of priority species were classified as tolerating mild to moderately brackish or saline conditions (categories 3 & 4), and were dominated by vertebrates (Table 11). The proportion of species intolerant of saline conditions was considerably greater than those that are able to withstand brackish conditions. It is widely acknowledged that the species richness of freshwater invertebrates is greater than those of brackish conditions (Bamber et al. 2001, Kefford et al. 2007, Lott et al. 2010, Palmer et al. 2010), due to the specific, often costly, adaptations required to withstand saline conditions. However, overall hydrological and saline complexity within an area, provides a wider range of niches and thus increases overall biodiversity (Bamber et al. 1992).

The proportions of tolerance categories were broadly similar between plant and invertebrate species, although slightly more priority invertebrates were intolerant of even mildly saline conditions and these observations are similar to others of saline influenced wetlands (Savage 1985). This was accentuated for particular groups of invertebrates, e.g. moths and spiders were particularly vulnerable to increases in salinity (97% and 81% respectively classified as category 1). True flies and beetles comprised relatively high proportions of the species able to tolerate brackish conditions.

Table 9. Cross-tabulation of the salinity and hydrological tolerances of all priority species recorded in the Broads since 1988, excluding gull species and species that could not be coded due to insufficient information. Values in brackets refer to the number of Broads Speciality species (entirely or largely restricted, primary stronghold)

		Salinity Tolerance Categories							
		0 (n/a)	**1 (freshwater)**	**2 (some saline influence)**	**3 (brackish)**	**4 (saline)**	Total	% of total	% of Specialities
Hydrological Tolerance Categories	**1 (dry)**	443	0	0	0	0	443	42.1	0.0
	2 (damp)	99 (3)	0	0	0	0	99	9.4	5.7
	3 (wet)	0	188 (25)	35 (3)	31 (3)	4	258	24.5	58.5
	3A (littoral)	0	43 (1)	11	7	14	75	7.1	1.9
	4 (aquatic)	0	54 (5)	13 (6)	14 (2)	23	104	9.9	24.5
	5 (part-aquatic)	0	34 (2)	19 (2)	11	6	70	6.6	7.5
	6 (landscape-scale)	0	2 (1)	0	1	1	4	0.4	1.9
	Total	542	321	78	64	48	**1053**		
	% of Total	51.5	30.5	7.4	6.1	4.6			
	% of Specialities	5.7	64.1	20.8	9.4	0			

Table 10. Percentage of species in each hydrological tolerance category by taxonomic group

Taxonomic grouping	Total priority species	Species coded for hydrological tolerance	% of the classified priority species						
			Category 1 (dry)	**Category 2** (damp)	**Category 3** (wet)	**Category 3A** (littoral)	**Category 4** (aquatic)	**Category 5** (part-aquatic)	**Category 6** (landscape scale)
Fungi And Lichen	24	21	**95.2**	4.8	0.0	0.0	0.0	0.0	0.0
Non-Vascular Plant	30	30	23.3	23.3	13.3	0.0	**40.0**	0.0	0.0
Vascular Plant	131	131	**58.8**	14.5	10.7	2.3	13.7	0.0	0.0
Plant and Fungi Subtotal	185	182	**57.1**	14.8	9.9	1.6	16.5	0.0	0.0
Speciality Subtotal	10	10		10.0	40.0	0.0	**50.0**	0.0	0.0
Spider	28	28	42.9	0.0	**53.6**	0.0	3.6	0.0	0.0
True Bug (Hemiptera)	34	34	14.7	5.9	**61.8**	5.9	11.8	0.0	0.0
Beetle (Coleoptera)	246	244	**32.4**	5.7	23.4	10.7	14.8	13.1	0.0
Moth	144	144	**66.0**	12.5	21.5	0.0	0.0	0.0	0.0
True Fly (Diptera)	173	161	18.6	18.6	**44.7**	9.9	0.0	8.1	0.0
Hymenopteran	49	49	**85.7**	2.0	8.2	0.0	0.0	0.0	4.1
Other Invertebrate	37	37	**37.8**	2.7	13.5	0.0	35.1	10.8	0.0
Invertebrate Subtotal	711	697	**39.7**	9.5	29.4	6.3	7.7	7.0	0.3
Speciality Subtotal	42	41		5.0	**62.5**	2.5	20.0	7.5	2.5
Birds And Fish	180	154	**32.5**	3.2	20.8	18.2	12.3	11.7	1.3
Other Vertebrates	20	20	**60.0**	5.0	15.0	0.0	5.0	15.0	0.0
Vertebrate Subtotal	200	174	**35.6**	3.4	20.1	16.1	11.5	12.1	1.1
Speciality Subtotal	2	2		0.0	**50.0**	0.0	0.0	**50.0**	0.0
Total	1096	**1053**	**42.1**	9.4	24.5	7.1	9.9	6.6	0.4
Speciality Total	54	53		5.8	**57.7**	1.9	25.0	7.7	1.9

Table 11. Percentage of species in each salinity tolerance category by taxonomic group

Taxonomic grouping	Total priority species	Species coded for salinity tolerance	% of the classified priority species			
			Salt Category 1 Freshwater	**Salt Category 2** Some saline influence	**Salt Category 3** Brackish	**Salt Category 4** Fully saline
Fungi And Lichen	24	0	-	-	-	-
Non-Vascular Plant	30	16	**62.5**	18.8	18.8	0.0
Vascular Plant	131	35	**68.6**	17.1	8.6	5.7
Plant and Fungi Subtotal	185	51	**66.7**	17.6	11.8	3.9
Speciality Subtotal	10	9	33.3	**55.6**	11.1	0.0
Spider (Araneae)	28	16	**81.3**	6.3	6.3	6.3
True Bug (Hemiptera)	34	27	**77.8**	7.4	14.8	0.0
Beetle (Coleoptera)	246	151	**75.5**	9.3	13.2	2.0
Moth	144	31	**96.8**	3.2	0.0	0.0
True Fly (Diptera)	173	101	**68.3**	13.9	17.8	0.0
Hymenopteran	49	6	**66.7**	33.3	0.0	0.0
Other Invertebrate	37	22	**68.2**	22.7	9.1	0.0
Invertebrate Subtotal	711	354	**75.1**	11.0	12.7	1.1
Speciality Subtotal	42	39	**78.9**	10.5	10.5	0.0
Birds And Fish	180	99	21.2	28.3	9.1	**41.4**
Other Vertebrates	20	7	0.0	28.6	**57.1**	14.3
Vertebrate Subtotal	200	106	19.8	28.3	12.3	**39.6**
Speciality Subtotal	2	2	0.0	**100.0**	0.0	0.0
Total	1096	511	**62.8**	15.3	12.5	9.4
Speciality Total	54	50	**67.3**	22.4	10.2	0.0

Distribution of priority species with varying tolerance of and vulnerability to salinity

The high quality fen sites in the Ant, Bure, Thurne and Mid-Yare support many species of all tolerance/vulnerability categories; this should be considered in relation to the relatively high density of recording in these areas.

Salt Tolerance Category 1 (vulnerable to saline influence)
High quality sites along the Ant and Bure are particularly important hotspots for priority freshwater species that are intolerant of slight saline influence, with other hotspots in the Hickling area, the Mid-Yare (including Strumpshaw, Rockland and Surlingham), Trinity Broads to the Muck Fleet, and Upton Broad (Figure 17, Figure 20). Lower, but nevertheless valuable, concentrations of freshwater dependent species are also found in the lower Waveney/Oulton Broad area.

This mapping study emphasises the vulnerability of existing important assemblages of freshwater and salt intolerant species in the Ant and Thurne to any projection of increased occurrence of saline incursion. Possible mitigation of the impacts of increased risk of saline incursion and river overtopping may be explored in terms of habitat improvement along minor rivers that feed into the key catchments, for example the Chet or Tas, but will depend on availability or potential to create suitable environmental conditions for these species. However, while Redgrave and Lopham Fens in the upper Waveney appear as an important hotspot, the intervening stretches along the Waveney appear to provide little connectivity of high value biota (Figure 17).

Salt tolerance Category 2 (slight saline influence)
Surprisingly, the distribution of hotspots for priority species tolerant of mildly saline conditions is very similar to that of freshwater, saline-intolerant species (Figure 18). The grazing marshes complexes of the lower Waveney contained proportionally more species tolerant of slight saline conditions than those in other categories. The richness of category 2 species is high in the Mid-Yare. Salinities in this area were thought to be higher previously, indicated by a number of species that probably relied on exposed mud at low tide (Shardlow 2007).

Salt tolerance Category 3 (mildly to moderately brackish)
Even for those priority species that are considered tolerant of brackish conditions (e.g. *Cerapheles terminates*), the Ant and Bure are notable hotspots (Figure 19). The species richness of brackish tolerant priority species increased in the Thurne, particularly the Hickling and Horsey area, compared to the relative richness of other categories. The richness of category 3 species in Breydon Water and grazing marsh to the north, and Langley and Belton marshes are also relatively higher.


Soft-winged flower beetle
Cerapheles terminatus
©Christoph Benisch

Salt tolerance Category 4 (fully saline)
Few species were categorised as tolerant of fully saline conditions and their distribution is therefore not specifically mapped, but is shown in Figure 20. One of the few invertebrates classified into this category is a wood-boring weevil *Pselactus spadix* (N:B), which is found in mid to high intertidal zones, dwelling in groynes and driftwood. It is able to tolerate infrequent submersion in seawater (Oevering and Pitman 2001).

Overall pattern of mapped saline vulnerability and tolerance

By considering the relative proportions of different salinity tolerance categories, rather than the absolute numbers of species in each category, a clearer pattern of saline influence emerges (Figure 20). Assemblages with a high proportion of freshwater-dependent species are particularly notable in the Ant, Bure and Mid-Yare. Assemblages with a higher proportion of priority species tolerant of slight saline influence are notable in the lower Bure and lower Waveney. Grazing marshes of the lower Yare are notable for the high proportion of species tolerant of brackish conditions. Assemblages in the Thurne are notable for the heterogeneity of salinity tolerances, with all classes represented. Brackish tolerant species notably form a high proportion of records at other scattered sites, particularly sites with lower overall richness, where scattered records of widely distributed vertebrates (e.g. Otter and Water Vole) influence this pattern.

Species highly tolerant of saline conditions (category 4) are entirely confined to areas at or very near the coast (Figure 20). Species tolerant of mild to moderately brackish (category 3) are more wide spread; however, Water Vole and Otter were both placed in this category and are relatively widespread and mobile species. If the distribution of brackish tolerant species is considered in relation to the total number of species at a location (inset Figure 20), then the higher relative proportions of brackish tolerant to freshwater species are more restricted to coastal or saline influenced areas. This is to be expected since it is widely known that physiological adaptations to saline tolerance are energetically costly and, as a result, saline-adapted species tend to be poor competitors in freshwater environments. This results in a spatial segregation of species across salinity gradients that is driven by competitively superior freshwater species displacing salt-tolerant species physically to saline conditions, whereas freshwater species are limited from saline environments because they do not have the relevant adaptations (e.g. Herbst 1999, Crain et al. 2004)

Even for those priority species that are considered tolerant of brackish conditions, the Ant and Bure are notable hotspots (Figure 19). The species richness of brackish tolerant priority species increased in the Thurne, particularly the Hickling and Horsey area, compared to the relative richness of other categories. The richness of category 3 species in Breydon Water and grazing marsh to the north, and Langley and Belton marshes are also relatively higher.

Few conductivity data were available for the complex of broads that include the Trinity Broads, Burgh Common and the Muck Fleet (Figure 16), but those that were obtained show that these wetlands have low conductivities despite relatively close proximity to the coast (Figure 16, 1997). This area is not subject to salt water percolation, unlike the Thurne catchment, and has numerous freshwater upwellings. This is reflected in the low proportion of saline tolerant (category 3) species (Figure 19, Figure 20).

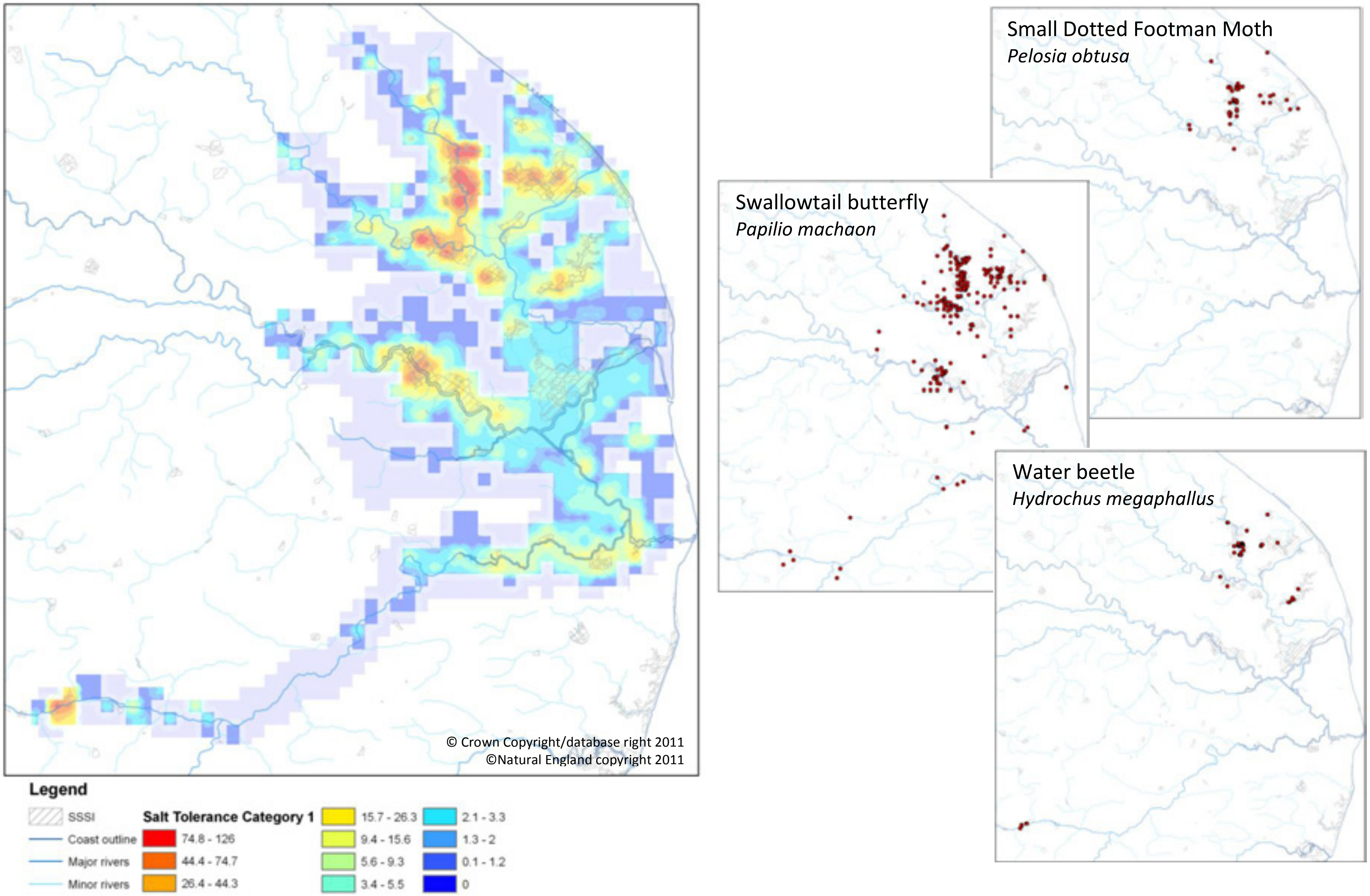


Figure 17. The distribution of priority species (numbers per km^2) classified as salt tolerance 1 (requiring freshwater (<800 µS/cm), intolerant of mild saline influence), represented as smoothed surface of species, with squares with no species as a semi-transparent overlay. The distribution of some example regional speciality species; Small Dotted Footman moth, *Pelosia obtuse* (RDB:EN, Entirely Restricted), Swallowtail butterfly *Papilio machaon* (RDB:NT, Largely Restricted) and water beetle, *Hydrochus megaphallus* (RDB:VU, Primary Stronghold) is also shown

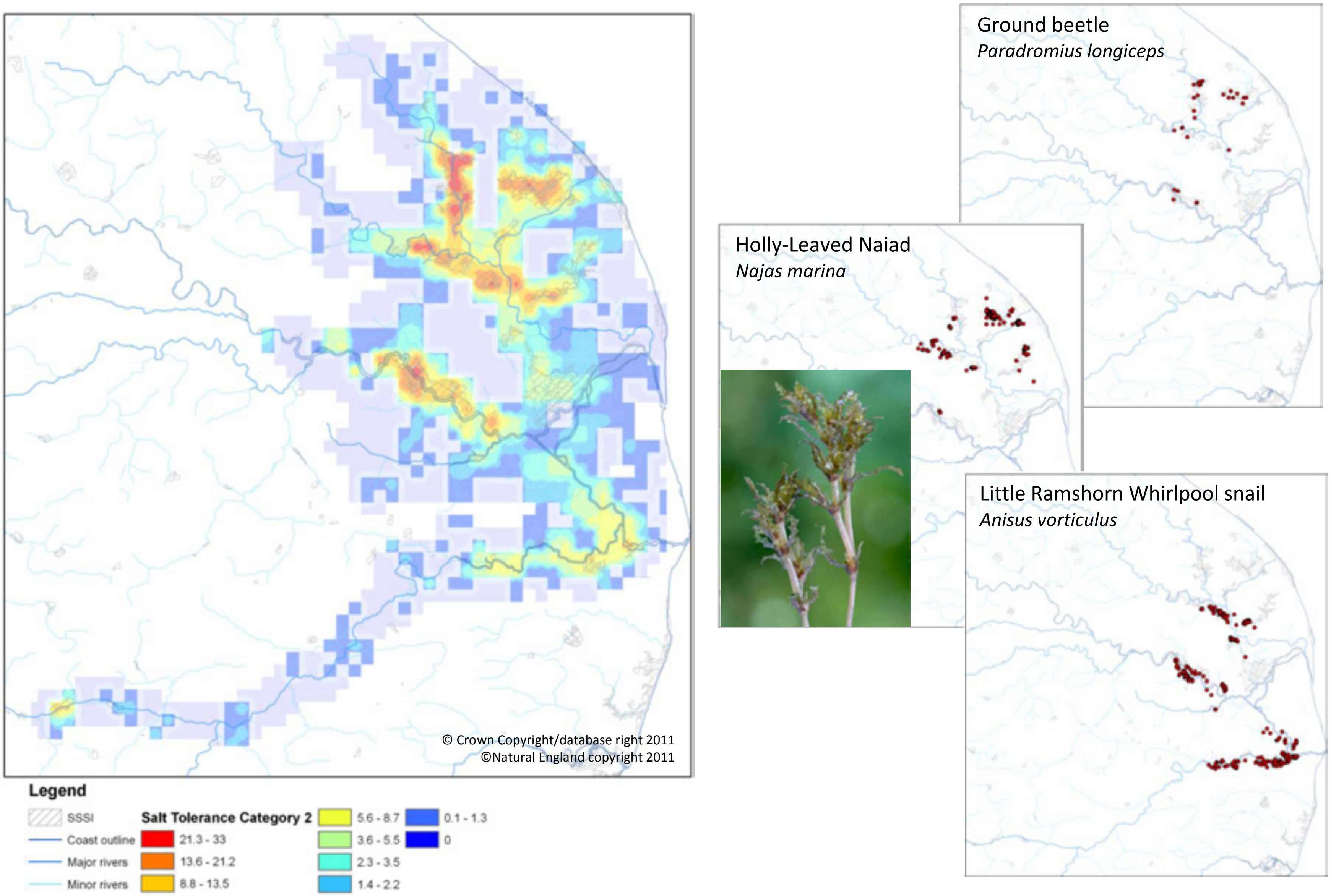


Figure 18. The distribution of priority species (numbers per km^2) classified as salt tolerance 2 (tolerant of slight saline influence (800-7,800 µS/cm)), represented as smoothed surface of species, with squares with no species as a semi-transparent overlay. The distribution of some example regional Broads Speciality species; ground beetle *Paradromius longiceps* (N:A), Holly-Leaved Naiad *Najas marina* (RDB:VU, S:NR, BAP, Entirely Restricted) and Little Ramshorn Whirlpool snail, *Anisus vorticulus* (RDB:VU, BAP, Largely Restricted) is also shown

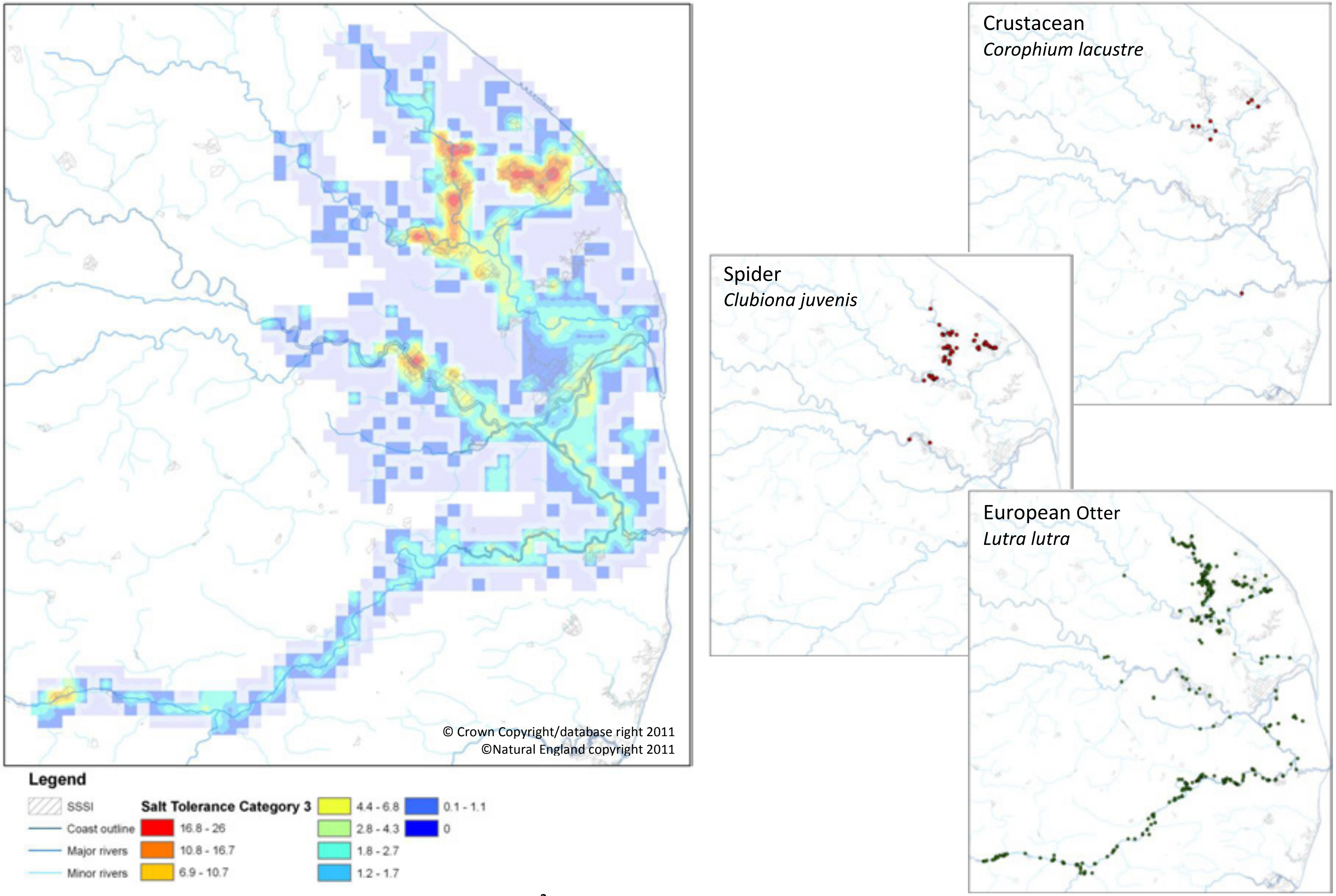


Figure 19. The distribution of priority species (numbers per km^2) classified as salt tolerance 3 (requiring or tolerating brackish conditions (7,800-28,100 µS/cm), represented as smoothed surface of species, with squares with no species as a semi-transparent overlay. The distribution of some example regional Broads Speciality species; crustacean *Corophium lacustre* (RDB:R, Primary Stronghold), spider *Clubiona juvenis* (RDB:VU, Primary Stronghold) and of the European Otter *Lutra lutra* (GRDB:NT, BAP), not a regional Speciality (therefore shown in green)

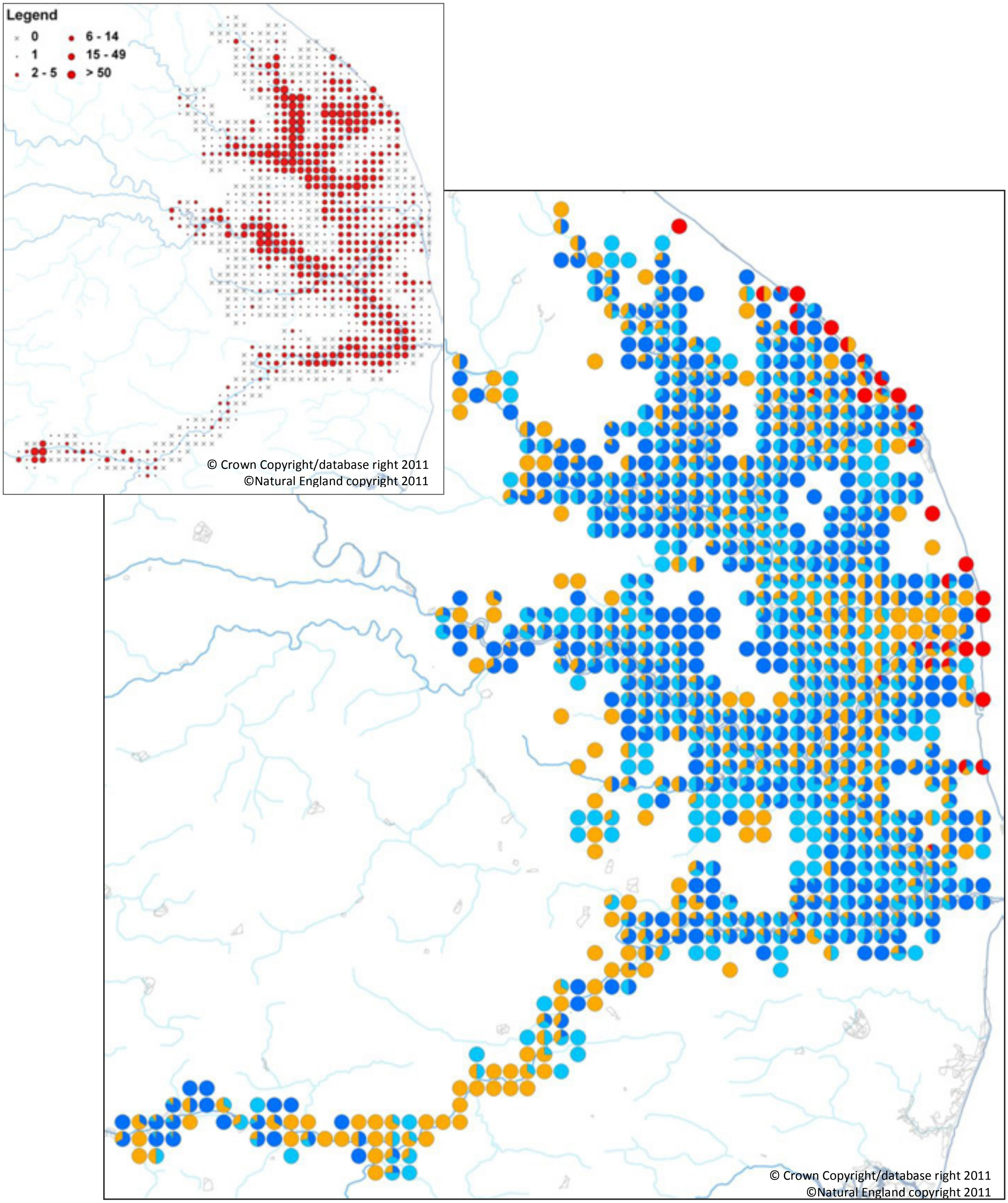
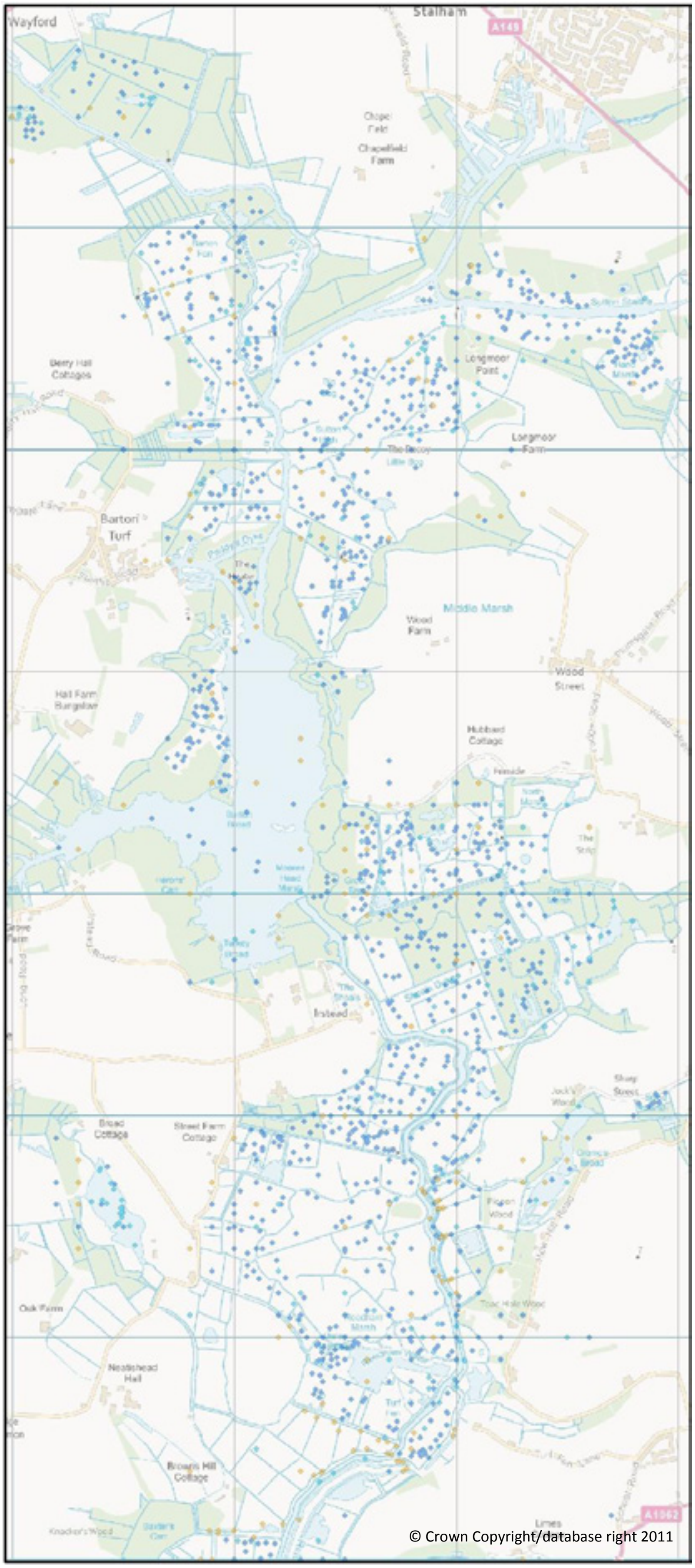


Figure 20. Distribution within the Broads of the proportion of the four salinity tolerance categories, sized in proportion to the number of species. Category 1 (freshwater): dark blue, Category 2 (slight brackish): light blue, Category 3 (brackish): orange, Category 4 (saline): red



Within areas of high richness, high interest and high surveillance intensity, discrete mapping at a greater than 1km resolution (e.g. 6-figure grid references or greater) can be used to show the occurrence of individual species and their corresponding tolerances. However, this technique for priority species is only possible in areas with an abundance of recording at high spatial resolution, e.g. locations of the Fen Ecological Survey (ELP 2010).

Discrete mapping of an area of the mid-Ant shows the location of species dependent on freshwater (presumed to be intolerant of, and vulnerable to, moderate saline influence) is quite widespread across the wetland areas (Figure 21). However, high densities of freshwater species are frequently in wetlands that are hydrologically isolated from the river systems. In comparison, brackish-tolerant species often occur in Broads, along or next to rivers and in grazing marsh dykes.

Figure 21. The tolerances for individual priority species observations mapped on a 1km grid for area surrounding Barton Broad in the Ant valley. Tolerances shown are: freshwater, tolerance category 1 (dark blue); some saline influence, tolerance category 2 (light blue); and brackish water species (orange). Points are not offset and underlying records may be obscured, thus not all records are visible

Full list of Recommendations

These recommendations have been guided and agreed by the steering group as worthy of further exploration, priority and timescale for action are suggested as follows.

<table>
<tr><th rowspan="2">Description</th><th rowspan="2">Suggested Completion date</th><th colspan="2">Prioritisation (1: highest, 3: lowest)</th></tr>
<tr><th>Importance</th><th>Urgency</th></tr>
<tr><td>A1: Develop strategic priorities to strengthen biological recording coverage in The Broads
A2: Increase understanding of status of priority species with no recent observations (post 1988)</td><td></td><td></td><td></td></tr>
<tr><td>A working group should be convened to decide taxonomic and site based priorities for further urgent recording. This working group should comprise; NBIS, SBRC, BA, NE, UEA, with consultation with landowners and others (e.g. NWT) regarding access potential. The working group should:
Create a shortlist of sites for urgent survey, that can focus effort by recorders and natural history groups (both national and local) and facilitate access.
Criteria will include:
the need to expand recording beyond those well-recorded, high-quality fen sites
the need to strengthen the evidence base for other fen sites, other under-recorded habitats (e.g. CWS grasslands, grazing marshes, wet woodland, fen carr), under-recorded sites (e.g. Halvergate, Muckfleet), particularly areas under-recorded for certain taxonomic groups (e.g. true flies, true bugs, spiders, molluscs)
presence or high abundance of axiophytes
potential values of sites,
quality of existing site information, both current recording effort and taxonomic coverage
access to site
consideration of the list of priority species for which no recent (post 1988) records exist, with judgement of: i) whether they are known to be lost, ii) species that should be removed from survey priority (e.g. ephemeral colonists, regionally extinct e.g. red squirrel, coypu, garden escapes), iii) whether individuals can be contacted who may have information on current status of the retained list, iv) known, historic, or likely sites to target for survey to improve knowledge of status of the retained list
The working group should complete the prioritisation process in advance of the 2012 recording season.</td><td>End Feb 2012</td><td>1</td><td>1</td></tr>
</table>

Subsequently, in winter 2012/13, the working group should reconvene to assess the achievement of recording in 2012, and whether there is a necessity to supplement this by commissioned surveys for target focal groups or sites.			
B: Maintaining a database for the future			
The database of collated records produced during the Biodiversity Audit of The Broads (BAB) will be provided by UEA to NBIS/SBRC who will then integrate this into their existing data-bases. The recording working party (see R1) should review the relative importance and value of un-digitised record sources identified through the BAB and prioritise these for subsequent capture (e.g. by BA and or NBIS volunteers) Further records should be collated through existing data capture and management protocols by NBIS / SBRC. All organisations commissioning surveys in the Broads should ensure that all surveys and records are provided to NBIS / SBRC in digital form We recommend that future research on biodiversity distributions or tolerance mapping extracts updated data from these organisations.. This will allow future mapping to be based on a revised and updated single central database.	Ongoing	2	4
C: Recognition for the biodiversity importance of The Broads			
Utilise the Broads Audit to further the national recognition of the biodiversity importance of The Broads by: ▪ achieving national press coverage for the results of the Biodiversity Audit of The Broads (BAB) ▪ subsequent press releases and publicity e.g. for individual Broads speciality species and nationally rare species for which NE declared extinct (e.g. when recent records are made) ▪ production of articles for popular natural history / conservation media e.g. Transactions of the Norfolk Naturalist Society, Tern, Natural World, British Wildlife	Oct - Dec 2012	1	1
D: Improve site networks for non-wetland habitats within The Broads			
County Council and Wildlife Trusts should conduct a review of existing County Wildlife Sites and Roadside Nature Reserves in the Broads area, to evaluate condition, threat, opportunities for enhancement, gaps, potential for additional expansion of the network. Re-survey of sites maybe needed. Ecological enhancement opportunity mapping of the Broads area should be undertaken to identify where gaps in the ecological network can be filled and where buffering of key non-wetland habitat areas and sites will be beneficial. This detailed work could be based on the broad ecological network mapping undertaken on behalf of the NBP in 2009.	Sept 2013	2	2
E: Improve strategic planning for non-wetland habitats			
In undertaking their statutory duties with regards to Planning, the Broads Authority should ensure adverse impacts on biodiversity are addressed in a manner to achieve the key strategic objectives of creating terrestrial habitats and buffering important wetlands. Developers should be encouraged to provide enhancements that support these key objectives and that contribute to coherent ecological networks. Biodiversity off-setting should be used to compensate for biodiversity loss, particularly within neighbouring districts to the Broads, where off-site measures may bring greater benefits in reaching key	Ongoing	2	2

objectives than can be provided by compensation within the development footprint.			
F: Understanding and monitoring of appropriate indicators of biodiversity			
Undertake (either by commissioning work or by offering a student dissertation) a desk study and analysis of data collated during the BAB, to explore the utility of commonly monitored species (e.g. birds, butterflies and dragonflies) to act as indicators or proxies of wider biodiversity, particularly of under-recorded species groups. Separately, or as part of the work above, undertake a desk study to assess the utility of *axiophytes* as indicators of wider biodiversity (e.g. invertebrate assemblages). The Audit database provides an excellent opportunity to compare the presence and/or abundance of these species, which are relatively easy to monitor, with other groups of species that are more time consuming to survey.	Sept 2013	2	3
G: Assess the utility of axiophytes as indicators of habitat quality and environmental change			
The value of axiophytes as monitoring tools has yet to be tested (Harrap & Ellis 2010). Undertake (either by commissioning work or by offering a student dissertation) a desk study to assess the value of axiophytes as monitoring tools of habitat quality and environmental change. Utilising the Audit species database and collated data of conductivity (plus other additional sources of conductivity measurements); i) using available literature, assess the tolerances of axiophytes; ii) compare the occurrence of axiophytes with the range in environmental measurements in order to validate the species tolerances; iii) at sites where plant data are available at a high spatial resolution, use axiophyte presence and abundance to explore environmental conditions.	Sept 2013	2	3
H: Long-term surveillance and monitoring of biodiversity and environmental conditions			
Establish a working group to propose a framework for a number of regular monitoring stations. Stations would include sites that are and are not likely to be subject to changes in salinity and/or hydrology and at different frequencies (these could include areas already subject to regular species recording), where both environmental and species information would be collected. This would provide understanding of both the ability of different species and assemblages to recover from incidents and the changes in assemblages that result from incidents of different duration, timing, severity and frequency. Undertake further work analysing the relationships between conductivity and salinity at different locations, and assess the thresholds at which these relationships have sufficiently small errors to allow conductivity to be a useful measure of salinity. This work should also include assessment, and where possible quantification, of other sources of chloride in the catchments.	End 2012	1	2
I: Exploring site specific temporal changes in species compositions			
Undertake (either by commissioning work or by offering M.Sc. dissertation) further analyses of the Broads Audit data set in order to examine potential	Jan 2013	3	3

changes in assemblages through time within intensively recorded catchments or sites (e.g. Wheatfen or Catfield), in relation to habitat quality and tolerances of priority assemblages. This work should utilise ISIS (Invertebrate Species-habitat Information System) to assess changes in invertebrate assemblages. Separately, or as part of the work above, Ellenberg values for plants should be used to map the distribution of all plant species (i.e. priorities and non-priorities) to assess changes in salinity. This work should build on that done in for the Fen ecological Survey. These should be validated by mapping in relation to conductivity data, where available.			
J: Priority species vulnerability and risk for potential mitigation and adaption activities			
Commission work to review priorities and understand species vulnerabilities to changes in hydrology and salinity, based on a criteria of; dispersal ability, current distribution, flood and saline incursion risk. A literature review of the dispersal abilities of different species/groups will assist in understanding the potential value of habitat creation and increased connectivity. This will identify which priorities are most vulnerable to risk and conservation will need to be addressed through habitat creation or even assisted migration. Furthermore, Defra guidelines require understanding of species and their dispersal abilities prior to discussion of the possibility of translocation. By examining risk and the current potential habitat suitability through elevation, hydrology and flooding envelopes, opportunities for habitat mitigation and creation can be identified and evaluated.	Sept 2013	1	1
K: Future landscape changes and its implications for biodiversity and ecosystem services			
Commission studies assessing the changes in biodiversity quality and value, the net gain and loss of different ecosystem services and their value under differing scenarios of major landscape change, e.g. the conversion of grazing marsh to arable agriculture or saltmarsh. Particular reference should be made to the vulnerable areas of habitats and biodiversity, and what would be the consequences of habitat changes. This would consider the following elements: quantitative audits of changes to ecosystem services (e.g. flood control, carbon capture, including economic assessments for the changes in agriculture); and analyses of the losses and gains of biodiversity.	Sept 2013	2	2

References

Anon (1958) The Venice system for the classification of marine waters according to salinity. Limnology and Oceanography 3: 246-347

Bamber RN, Batten SD, Sheader M, Bridgwater (1992) On the ecology of brackish water lagoons in Great Britain. Aquatic Conservation: Marine and Freshwater Ecosystems, 2: 1099-0755

Bamber RN, Gilliland PM, Shardlow EA (2001) Saline Lagoons: A Guide to their Management and Creation. English Nature, Peterborough, UK, 95 pp. ISBN 1 85716 573 X.

Broads Authority (2004) Broads Plan 2004: A strategic plan to manage the Norfolk and Suffolk Broads. Broads Authority, Norwich

Broads Authority (2009) Broads Authority Biodiversity Action Plan: Framework Document (2009). Norfolk Wildlife Services & Broads Authority, Norwich

Broads Authority (2010) Relationship between Electrical Conductivity (EC-µS/cm), salinity concentration, chloride concentration and Practical Salinity Units. Broads Authority, Norwich

Broads Authority (2011) Broads Plan 2011: A strategic plan to manage the Norfolk and Suffolk Broads. Broads Authority, Norwich

Broads Authority (2011) Draft Broads Climate Change Adaptation Plan. Broads Authority, Norwich

Balfour-Browne F (1940, 1950, 1958) British Water Beetles: Volumes I-III. Ray Society, London

Brown A, Brotherton P, Pearce P, Perry S, Pearson H, Radley D, Measures G, Townshend T, (ed.) (2010) Lost Life: England's lost and threatened species. Natural England, Peterborough.

Crain CM, Silliman GM, Bertness SL, Bertness MD (2004) Physcial and biotic drivers of plant distribution across estuarine salinity gradients. Ecology 85: 2539-2549

Dolman PM, Panter CJ, Mossman HL (2010) Securing Biodiversity in Breckland. Guidance for Conservation and Research. First Report of the Breckland Biodiversity Audit. University of East Anglia, Norwich.

ELP (2010) Fen Plant Communities of Broadland: Results of a comprehensive survey 2005-2009. Report to the Broads Authority, Norwich

Everard M (2005) Water Meadows: Living Treasures in the English Landscape. Forrest text, Tresaith.

Falk S (1991a) A Review of the Scarce and Threatened Bees, Wasps and Ants of Great Britain. Research and Survey in Nature Conservation. Joint Nature Conservation Committee, Peterborough.

Falk S (1991b) A Review of the Scarce and Threatened Flies of Great Britain. Research and Survey in Nature Conservation. Joint Nature Conservation Committee, Peterborough.

Foster G, Eyre MD (1992) Classification and Ranking of Water Beetle Communities. Joint Nature Conservation Committee, Peterborough.

Fuller R, Smith G, Sanderson J, Hill R, Thomson A, Cox R, Brown N, Clarke R, Rothery P, Gerard F (2002) Countryside Survey 2000 Module 7: Land Cover Map 2000 Final Report. Centre for Ecology and Hydrology, Monks Wood.

Harrap S, Ellis B (2010) Axiophytes: A Tool for Conservation. Natterjack: The quarterly bulletin of the Norfolk & Norwich Naturalists' Society 108: 14-16

Herbst DB (1999) Biogeography and physiological adaptations of brine fly genus Ephydra (Ditera: Ephydridae) in saline waters of the Great Basin. Great Basin Naturalist 59: 217-135

Hyman PS, Parsons MS (1992) Review of the Scarce and Threatened Coleoptera of Great Britain, Part 1/2. UK Nature Conservation Series No.3. Peterborough.

Jackson MJ, Howlett DJ (1999) Freshwater Molluscs of the River Waveney Grazing Marshes. A survey carried out during the summer of 1997. Broads Authority Report. BARS 18.

JNCC (2011) List of species designations. http://www.jncc.gov.uk/page-3408; latest update accessed on February 2011.

Kefford B, Dunlop J, Nugegoda D, Choy S (2007) Understanding salinity thresholds in freshwater biodiversity: freshwater to saline transition. In Lovett S, Price P & Edgar B (eds) Salt, Nutrient, Sediment and Interactions: Findings from the National River Contaminants Program, Land & Water, Australia.

Kerney M (1999) Atlas of Land and Freshwater Molluscs of Britain and Ireland. Harley Books, Colchester.

Lee P, Scott D (2007) East Anglian Wetland Bees and Wasps. Hymettus Ltd, Midhurst.

Lee P, Saunders P, Scott D (2008) East Anglian Wetland Bees and Wasps. Hymettus Ltd, Midhurst.

Lott DA, Drake CM, Lee P (2010) Broads Fen Invertebrate Survey. Report to the Broads Authority, Norwich.

Meredith TC, Grubb PJ (1993) *Peucedanum palustre* (L.) Moench. Journal of Ecology. 81: 813-826.

Murphy JM, Sexton DMH, Jenkins GJ, Booth BBB, Brown CC, Clark RT, Collins M, Harris GR, Kendon EJ, Betts RA, Brown SJ, Humphrey KA, McCarthy MP, McDonald RE, Stephens A, Wallace C, Warren R, Wilby R, Wood R (2009) UK Climate Projections Science Report: Climate change projections. Met Office Hadley Centre, Exeter.

NBIS (2008) Norfolk Biodiversity Action Plan Species Data Audit. Norfolk Biodiversity Information Service, Norwich.

Newbold C (1997) Water level requirements of wetland plants and animals. English Nature Freshwater Series. Peterborough.

Oevering P, Pitman AJ (2001) Substrate preferences by the intertidal wood boring weevil *Pselactus spadix* (Herbst). International Biodeterioration & Biodegradation 50 (1):11-15.

Palmer M, Drake M, Stewart N (2010) A manual for the survey and evaluation of the aquatic plant and invertebrate assemblages of grazing marsh ditch systems. Buglife, Peterborough.

Savage, AA (1985) The Biology and Management of an Inland Saline Lake. Biological Conservation 31, 107 123.

Shardlow, M (2007) A summary of the invertebrate fauna of the Mid-Yare Valley 1889-1994. Buglife Unpublished report.

Strudwick T (2008) A survey of *Odynerus simillimus* nest sites in the Norfolk Broads in 2008. Hymettus Ltd, Midhurst

Taylor M, Marchant JH (2011) The Norfolk Bird Atlas: Summer and Winter Distributions 1999-2007. British Trust for Ornithology, Thetford.

UNEP-WCMC, Cambridge (2011) UK National Ecosystem Assessment: understanding nature's value to society synthesis of the key findings http://uknea.unep-wcmc.org.

Williams, T (1997) The Norfolk Broads: A Landscape History. 185 pp. Manchester University Press, Manchester.

Wotton S, Lodge C, McIntyre R, Schmitt S, Gregory R, Brown A (2010) Bittern *Botaurus stellaris* monitoring in the UK: Summary of the 2010 breeding season. RSPB & Natural England, Sandy & Peterborough.