

## Scientific study in the Loch Lomond and Trossachs area, Scotland

C.E. Adams<sup>1\*</sup>, R. Smith<sup>1</sup>, W. El Bestawy<sup>1</sup>, J.R. Rodger<sup>1</sup>, H.M. Honkanen<sup>1</sup>, P.S. Maitland<sup>2</sup> & S. White<sup>3</sup>

<sup>1</sup> Scottish Centre for Ecology and the Natural Environment, Rowardennan G63 OAW

<sup>2</sup> Nether Sunnyside, Haddington EH41 4NR

<sup>3</sup> Institute of Biodiversity, Animal Health and Comparative Medicine, Graham Kerr Building, University of Glasgow, Glasgow G12 8QQ

\*E-mail: [colin.adams@glasgow.ac.uk](mailto:colin.adams@glasgow.ac.uk)

### ABSTRACT

The natural environment of the Loch Lomondside area, Scotland is exceptionally well-studied. Here we describe a project to catalogue publications that describe these studies, and to form a living database of references. We recorded 1,436 references from the mainstream scientific literature and reports from the “grey literature”. The taxonomic groups and habitats studied were highly skewed. Faunal studies were considerably commoner than those of flora; studies on vertebrate species were commoner than those on invertebrate species; fish and birds were more commonly studied than other vertebrate groups. Reports of studies on terrestrial ecosystems were more frequent than those on aquatic systems. Amongst freshwater species, some groups were very poorly represented (e.g. Rotifera, Hydracarina, Diptera, Nematoda, Microturbellaria and Tardigrada). Many studies have made very significant contributions to understanding the mechanisms that operate in the natural environment. The underlying reasons for the important contributions that the Loch Lomondside area has made to natural science are discussed.

### INTRODUCTION

As a platform for naturalists and scientists to investigate the patterns of the natural world and the processes that drive it, Loch Lomond, Scotland punches well above its weight. A search of the Web of Science databases of published literature yields 474 publications with “Lomond” in the title, abstract or keywords from the years 1864 to 2021 (excluding those concerning the glacial readvance known as the Loch Lomond stadial). This contrasts with 425 for Loch Ness (the number for which decreases to 305 if the, arguably non-scientific, publications relating to the Loch Ness monster are removed) and 279 for Loch Leven. In the wider U.K., this publication rate for studies on freshwaters is exceeded only by Lake Windermere (494 publications), where since 1931 the Freshwater Biological Association (FBA) has been based on its shores. For many years, the FBA was the major force driving high quality fundamental science of internationally high standing on freshwater systems; later the freshwater research based there was conducted by government science institutes, initially through the Institute of Freshwater Ecology and latterly by the Centre for Ecology and Hydrology, until

2004 when this moved on to the Lancaster University campus.

Thus, Loch Lomond can reasonably lay claim to be the most studied lake ecosystem in Scotland and the second most studied in the U.K. Here, we describe the outcome of a project to draw together information on studies that underpin that claim and to make this information available to scientists, naturalists and the wider public.

### METHODS

With funding from the Glasgow Natural History Society through the Blodwen Lloyd Binns grant scheme, we compiled a bibliography of published scientific literature on Loch Lomond and its wider catchment. The current bibliography was founded on work begun by one of the authors here (PSM) which provided references in the field of freshwater biology around two decades ago (Maitland *et al.*, 2001). Recognising that the value of such work may be enhanced by extending the geographic range to include the Trossachs area, we have included any published studies that were wholly, or partly, conducted in the geographic area that is very approximately bounded by the Loch Lomond and the Trossachs National Park, an area covering 1,865 km<sup>2</sup> (Loch Lomond & The Trossachs National Park, 2021). In addition, we considerably extend the scope of topics to cover terrestrial and in some cases marine ecosystems.

Included in the database is literature published in peer-reviewed, national and international scientific journals, as well as less accessible and more difficult to find publications in the “grey” literature. This comprises government and non-governmental agency reports, including both material subject to peer-review and not peer-reviewed. We also include post-graduate theses, most of which are now either in the public domain or accessible through the academic institutions to which they were submitted. Although they have the potential to make very insightful contributions to our understanding of the natural world, we do not include studies conducted by undergraduates as Honours projects. This is in part because these are examinable documents usually subject to embargo but also because there is (as yet) no way to consistently capture information on where, and when, such studies are conducted.

In addition, we were also selective in the literature topics that we covered. Our aim was to capture references describing scientific studies on the natural world conducted in the defined study area. Thus, we covered obvious broad topics such as ecology, chemistry and geology. We also included topics such as physics and parasite and disease ecology where this pertained to the natural environment. References relating to geographic topics such as land use, forestry, fisheries, hydrology, meteorology, planning, land use and tourism, were included where it was clear that the study topic was relevant to the natural environment.

We did not include the vast literature on topics that did not contribute to a scientific understanding of the mechanisms in the natural world. Despite their ability to communicate an emotional perception of the natural world, we did not include references to poetry, song, music, novels or other creative writing. Also excluded were works of non-fiction focused on hobbies or pastimes, travelogues, landscape descriptions and references to historical studies (cultural, social or political), with the exception of a few cases where they provided insights into the processes in natural world.

We populated our database beginning with the references in the original database from 2001 (Maitland *et al.*, 2001), which comprises 640 references, and then added to this by searching Web of Science, Google Scholar and the Google search engine to search more widely. The process was completed with the final electronic searches undertaken in summer of 2021. We manually scoured hard copies of smaller national natural history and environmental journals which are not included in the Science Citation Index or Web of Science. For a number of key publications, we searched their citations lists to add to the database.

## RESULTS

### General comments on the literature

In total, we have recorded 1,436 references covering a wide range of topics pertaining to the natural world in Loch Lomondside and the Trossachs. A breakdown of references by subject topic, habitat and taxonomic group is provided (Table 1). It is informative to examine how much attention has been given to topics by previous studies, not simply to identify what has been covered but, more importantly, to identify the areas that are less well known.

The coverage of studies represented in the literature was markedly skewed across taxonomic groups, topics and habitats. References relating to study of the aquatic environment dominated those of studies on terrestrial systems by a factor of three. Unsurprisingly, given the study selection criteria, studies that were primarily ecological in nature vastly outnumbered those that were geographical or from the social sciences. There were four times as many studies looking at fauna of the region than those on the flora. Of all animal studies, 78% looked at vertebrates compared with 22% on invertebrates. Amongst the vertebrate studies, fish and bird studies dominated (88%) compared with other

groups. Where it was possible to determine the context for the study, applied conservation was the commonest reason (65%) given for the background to the study.

Important amongst the assembled references are six major monographs on aspects of the natural world in the Loch Lomond and Trossachs area. Two of these are by a single author: Maitland (1966) is a highly detailed account of the ecology of the Endrick Water (which drains the south east of the Lomond catchment) resulting from an intensive three-year study of the invertebrate and vertebrate fauna there; whereas Mitchell (2001) is a highly authoritative summary of knowledge of the natural history, diversity and land use changes of the area derived from the insight accrued from decades of work by the author.

The remaining four are multi-author monographs. Tippet (1974) is a comprehensive description of the natural history of the Loch Lomondside area, covering a range of topics including geology, terrestrial and freshwater flora and fauna, archaeology, local history, and land and water use. Murphy *et al.* (1994) comprises a collection of papers emanating from a symposium on Loch Lomond ecology held in 1992 to celebrate 25 years of research at the University of Glasgow's field station at Rowardennan on east Loch Lomondside. The topics in these 19 papers by 29 authors range from loch eutrophication and sediment chemistry through plankton, invertebrate, fish and vegetation ecology, to geology and hydrology. Slack (1957) is a selected summary of research work conducted at the University of Glasgow's field station at Rosdhu on west Loch Lomondside, between 1946 and 1957 (see Maitland & Hamilton, 1994). It includes an eclectic mix of chapters on the topography, physical and chemical nature of Loch Lomond and its aquatic fauna, the invertebrate communities of a well-studied offshore reef, gastropod ecology, biting midges, the basic biology of the powan (*Coregonus lavaretus*), and the parasites of fish. Downie & Weddle (2005) consists of the proceedings of a 2004 conference on the natural history of Loch Lomond and the Trossachs. The nine articles cover a wide range of topics from flora and fauna to practical wildlife management.

Several authors have made very considerable contributions to the scientific literature of the area. Notable amongst these is John Mitchell who for 27 years was in charge of the Endrick Mouth National Nature Reserve and who contributed 126 publications to the database, considerably more than any other author.

### Important science that has resulted from studies in the Loch Lomond area

Many of the studies captured in the bibliography described here have had an impact on our understanding of the mechanisms that operate in the natural world well beyond the study area. A comprehensive analysis of the enormous range and depth of science that has emanated from this area is beyond the scope of this current paper but to provide a flavour of the range of such work we describe a few of these here.

Study topic	Habitat Type	Plant*	Invertebrate	Vertebrate	General Field
Ecology (921)	Aquatic (876)	Plants (182)	Insect (60)	Fish (271)	Conservation (483)
Geography (247)	Terrestrial (279)		Mollusc (18)	Bird (244)	Management (230)
Social Science (154)			Crustacean (9)	Mammal (51)	Pure Science (35)
Geology (89)			Other (81)	Reptile (9)	
Chemistry (69)				Amphibian (6)	
Physics (27)				Other (7)	
Biology (11)					

**Table 1.** The subject, habitat type and taxonomic breakdown of the 1,436 references to scientific publications on the natural world from the Loch Lomond and Trossachs area included in the database to date. \*"Plant" here includes vascular and non-vascular plants.

Loch Lomond was one of the first lakes in the world to have the pattern of temperature change with depth described (in 1812). Although commonplace today using electronic thermometers, in 1812 (Leslie, 1838) a complex registering thermometer was required to take a temperature measurement at depth without the reading being altered by the temperature of the water above as it was retrieved to the boat.

Bathymetric surveys of Loch Lomond and Loch Awe in 1861 by the Royal Navy, under the direction of Captain H.C. Otter, were the first systematic bathymetric surveys of Scottish freshwater lochs. This work was conducted under the auspices of improving navigation for shipping (Murray & Pullar, 1900). It was a further 40 years before surveying of a further 562 lochs around Scotland began, arguably laying the foundation for the most comprehensive freshwater study ever undertaken in the U.K. (Murray & Pullar, 1910).

The detailed work of Maitland (1966) on invertebrate community succession along a stream channel continuum conducted in the Endrick Water provided a major strand of the empirical evidence for the articulation of the biological elements of the River Continuum Concept, a fundamental concept in freshwater science, some 25 years later (Vannote *et al.*, 1980).

The first report of a seiche, a periodic short duration oscillation of the water in a lake, resulting from an earthquake, was described from Loch Lomond in the aftermath of the Lisbon earthquake on the 1st November 1755 (Loch Lomond was *ca.* 2,000 km from the epicentre of the earthquake) (Anonymous, 1755). The period of oscillation was around 10 minutes and the amplitude of water height change over this time about 75 cm (Chrystal, 1910). This observation was made 135 years before the term seiche was first coined by the famous Swiss hydrologist Francois-Alphose Forel (Forel, 1886).

In more recent times Pollock *et al.* (2017) showed a very strong effect of urbanisation on blue tit (*Cyanistes*

*caeruleus*) breeding success, which was five times lower in urban areas compared with Loch Lomondside, and linked this to the quality of available food. Hume *et al.* (2018) used molecular genetics techniques to disentangle the evolutionary origins of a rare and protected form of lamprey found in the Lomond catchment and only a few other places in the world. A highly protected fish - the powan *Coregonus lavaretus* - from Loch Lomond and Loch Eck formed an important part of a study to address questions about intra-specific structuring, the very first signs of the emergence of new biodiversity. Crotti *et al.* (2020) sampled powan from Lochs Lomond and Eck and were able to describe complex patterns of genetic structuring across the species. They were able to show how novel diversity has emerged and they put this into the context of the conservation needs for this species.

James *et al.* (2011) published an important study on the role of passerine birds as hosts of ticks and the transmission of *Borrelia burgdorferi*, the agent of Lyme disease. The vast majority of previous research having been on the role of mammals in the transmission of this disease, there is very little in the scientific literature on the importance the role birds may also play in Lyme disease transmission. Another important recent publication is that of Jerem *et al.* (2015) which describes a newly developed non-invasive technique employing thermal imaging technology for measuring stress in wild birds. Whilst the majority of the vertebrate research at Loch Lomond has focused on fish and birds, Muir *et al.* (2014) uses molecular techniques to study adaptation to altitude in the common frog (*Rana temporaria*).

On a less serious note, it is fascinating to scroll through some of the short notes dating back to the 1850s to find records of exotic organisms such as Bonaparte's gull (*Chroicocephalus philadelphia*) (Leith, 1851), loggerhead turtle (*Caretta caretta*) (Gray & Smee, 1861), ruby-crowned kinglet/wren (*Corthylio calendula*) (Lumsden, 1904; Mitchell, 1983,1991) although the wild provenance of this bird has not been confirmed (Forrester *et al.* 2007), and pomarine skua (*Stercorarius pomarinus*) (Kirk, 1903).

### **Why is the Loch Lomond area so well studied?**

It is clear that the terrestrial and aquatic habitats of the study area defined here have received disproportionately high research attention compared with many other places. There are a number of reasons why this might be so.

The Loch Lomond area is clearly an area of high biodiversity. Around 540 species of flowering plants and ferns comprising 25% of all U.K. species (Idle, 1974) and 31 species (49%) of the 64 native and naturalised mammals (excluding vagrants, marine species and island endemics) (Mitchell, 1974; Mammal Society, 2020) are found on Loch Lomondside. In freshwater, Loch Lomond supports the highest diversity of native fish species of any Scottish loch. This comprises 65% (17 species) of the native freshwater fish fauna of Scotland (Maitland *et al.*, 2000). Although some groups of freshwater invertebrates have been recorded only poorly or not at all (particularly Rotifera, Hydracarina, Diptera, Nematoda, Microturbellaria, Tardigrada), 450 freshwater species of the 3,500 known from the U.K. have been recorded there (Adams *et al.*, 1990). All of this points towards a highly diverse flora and fauna of this area.

There is no doubt that this high diversity is, in part, a result of the area being bisected by the Highland Boundary Fault. This major fault line marks the separation of the distinct geologies of the Scottish Highlands from that of the Central Lowlands. Loch Lomond is the only major freshwater body straddling this fault. As a result, Loch Lomond and its catchment are partly in the low-lying, nutrient-rich, central lowlands and partly in the nutrient-poor highlands. This feature creates very considerable habitat diversity in the loch itself but also within the wider catchment, which certainly contributes to the species richness of the area. Thus Loch Lomondside is where the southern edge of more northerly species coincide with the northerly edge of more southerly species (Idle, 1974; Maitland *et al.*, 2000)

There is also a considerable number of species recorded from the study area that are relatively rare, in a national or international context. Table 2 lists those for which there is some published information. Twenty-four species are listed, along with some information explaining their inclusion here. Notable amongst these is the Lomond dock (*Rumex aquaticus*), which is known only from the study area, and an abyssal oligochaete, the Lomond worm (*Arcteonais lomondi*) (Martin, 1907), originally described from samples from Loch Lomond and with a very limited distribution in the U.K. It is a little unclear whether the presence of these rare species has stimulated research interest in the Loch Lomond area or if we know of the existence of these species only because of the focus on research there; a combination of both effects is the most likely.

One factor that has certainly stimulated scientific investigation of the area has been the establishment of a permanent research base there. The University of

Glasgow has operated a field research station on Loch Lomond continuously since 1946. Initially on the west of Loch Lomond at Rossdhu, after 1964 this moved to purpose-built facilities on east Loch Lomondside at Rowardennan (Maitland & Hamilton, 1994). Used as a base for field research, academic and research staff and research students from the University of Glasgow and their national and international collaborators have made a considerable contribution to understanding the mechanisms driving ecological processes using local study systems. Of the references listed in the bibliography detailed here, 399 have resulted directly from work conducted at the Scottish Centre for Ecology and the Natural Environment and its predecessor, the University Field Station.

The high diversity and presence of rare species have resulted in a number of designations which are related to the conservation of nature. There are 67 formally designated sites. One important site, the area around the mouth of the Endrick Water, where it discharges into the south-east corner of Loch Lomond, carries eight designations for its special features. The area is a Site of Special Scientific Interest, a Special Area for Conservation, a Special Protection Area, a Ramsar site, a National Scenic Area, a National Nature Reserve, in a National Park and an RSPB Nature Reserve.

### **The bibliography**

The bibliography of references on the study area described above is undoubtedly incomplete. It is impossible to locate all relevant references, especially those in the more difficult grey literature. The law of diminishing returns has required us to bring active searching for additional references to a close. In addition, new studies relevant to the area are emerging monthly. We thus regard the bibliography as a living entity that can and should be added to, amended and expanded. The bibliography is available in a format that can be utilised by those who use reference management software (Bibtex). In addition, we also make the bibliography entries available in the near-universal pdf format, readers for which are freely available and these have search functions to aid in finding references of interest to the user.

These versions are available at: [https://drive.google.com/drive/folders/1NHytQQY8rccVYfaqUcF8tmVLBD\\_4g2zp?usp=sharing](https://drive.google.com/drive/folders/1NHytQQY8rccVYfaqUcF8tmVLBD_4g2zp?usp=sharing)

The bibliography is inevitably out of date, even as you read this; new science and knowledge are being generated constantly. It is the authors' intention to update the bibliography periodically. If you find appropriate references that can be added to this database, please do send them to: [lomond.biblio@gmail.com](mailto:lomond.biblio@gmail.com).

### **ACKNOWLEDGEMENT**

We thank Dr Jennifer Dodd for comments on an earlier draft of this paper.

<b>Scientific Name</b>	<b>Common Name</b>	<b>Description</b>
<i>Arctonais lomondi</i>	<b>Lomond worm</b>	Found in the profundal mud, this worm was a species new to science discovered in Loch Lomond, hence the specific name “ <i>lomondi</i> ”. Later discovered also in Loch Morar, this species occurs nowhere else in Britain (Maitland <i>et al.</i> , 2001).
<i>Antrobathynella natans</i>	<b>subterranean (interstitial) crustacean</b>	A crustacean found living only in the interstitial spaces in groundwater, this species is only recorded in Scotland in the gravel of the Altquhur burn, a tributary of the Endrick Water (Maitland, 1962). Originally identified as <i>Bathynella natans</i> , the species has been moved to the genus <i>Antrobathynella</i> (Serban 1973). A re-examination of the original specimens lodged in the Natural History Museum by Proudlove <i>et al.</i> (2003), suggest that they may be <i>Antrobathynella stammeri</i> . However, this identification remains uncertain. The habitat in which these specimens were found is highly valued as a building material, and thus the species is at risk from gravel excavation and extraction (Maitland, 1962). Two subsequent attempts to find the species at the original site in the last decade have failed (J. Dodd, pers. comm.)
<i>Bithynia leachii</i>	<b>gastropod mollusc</b>	This species is a stenotopic freshwater snail restricted to still, high quality waterbodies (Global Biodiversity Information Facility, 2021). Its presence in Loch Lomond is unexpected given its few known localities in Scotland and it is a suspected introduction from southern lakes (Mitchell, 2001).
<i>Pisidium conventus</i>	<b>bivalve mollusc</b>	<i>P. conventus</i> is a small bivalve mollusc occurring exclusively in the deepest waters of Loch Lomond - the “Tarbet Deep” (Hunter & Slack, 1958). The species is an excellent example of an Arctic relict species found primarily in the profundal areas at depths of 190 m (Maitland & Adams, 2005).
<i>Cordulia aenea</i>	<b>downy emerald</b>	<i>C. aenea</i> exists in only three scattered populations within Scotland including Loch Lomond and the Dubh Lochan (NBN Atlas, 2021a).
<i>Somatochlora arctica</i>	<b>northern emerald</b>	This uncommon dragonfly is confined to scattered populations in north-west Scotland and Ireland, although commoner on the European continent (NBN Atlas, 2021b). Its rarity is partially a consequence of lacking suitable habitat and specific breeding conditions - oligotrophic pools, particularly where sphagnum is present and in close proximity to trees with a lack of open spaces (British Dragonfly Society, 2021).
<i>Lampert fluviatilis</i>	<b>lake-dwelling parasitic river lamprey</b>	<i>L. fluviatilis</i> , unlike other populations of river lamprey in Scotland, a Loch Lomond population remains in freshwater throughout its entire lifecycle, feeding parasitically on freshwater fish (mostly powan) rather than migrating to sea. This rare life history form is a feature of interest in the Endrick Water SAC designation (NatureScot, 2018).
<i>Coregonus lavaretus</i>	<b>powan</b>	The powan may be Scotland’s rarest freshwater fish and is an assumed glacial relict species. It is endemic to only two lochs in Scotland, Lomond and Eck, but exists as conservation refuge populations in other water bodies. Although populations are relatively healthy, in recent years the threat of ova predation from the invasive non-native <i>Gymnocephalus cernuus</i> in Loch Lomond and habitat degradation, have made it a priority species for the U.K. Biodiversity Action plan and it is protected under the Wildlife and Countryside Act 1981 (Adams & Tippett, 1991; Lyle <i>et al.</i> , 2016).

<i>Salvelinus alpinus</i>	<b>polymorphic Arctic charr</b>	<i>S. alpinus</i> is another species that invaded freshwater as the last ice age came to an end. Although not found in Loch Lomond itself, this species is recorded throughout the study area (NatureScot, 2021) and is important as a study species to investigate evolutionary questions and its extreme variation is of high conservation interest (Maitland & Adams, 2005).
<i>Rumex aquaticus</i>	<b>Lomond dock/ Scottish dock</b>	<i>R. aquaticus</i> is a perennial plant endemic only to Loch Lomondside. Preferring periodically inundated low-lying ground, it forms large colonies, particularly around Balmaha (Maitland <i>et al.</i> , 2001). Although not discovered until 1935, the species has medicinal properties (Grieve, 1984).
<i>Anser albifrons</i>	<b>Greenland white- fronted goose</b>	<i>A. albifrons</i> began wintering in Loch Lomond in the 1960s, following migration from summer breeding in Greenland (Mitchell, 1994). On the RSPB red-list, the flock of 200 birds that visit the Endrick SSSI annually account for 1% of the total population and are thus of high conservation value (NatureScot, 2018).
<i>Collema dichotomum</i>	<b>river jelly lichen</b>	<i>C. dichotomum</i> is a cyanobacteria-containing jelly lichen known only in eleven 10 km squares within the U.K. (NBN Atlas, 2021c). This lichen is classified as vulnerable and protected under the Wildlife and Countryside act (1981). It is sensitive to eutrophication and is in decline. Threats include replacement by algal species, pollution and water abstraction for hydroelectric schemes (Air Pollution Information System, 2011; NBN Atlas, 2021c). Its continuing presence on the River Endrick reflects the high ecological status of its water and lack of anthropogenic modification.
<i>Carex elongata</i>	<b>elongated sedge</b>	<i>C. elongata</i> is sparsely distributed throughout Britain and thought lost to Scotland until rediscovered on Loch Lomondside in 1967; this is now one of only four sites in the country (Mitchell, 2001). The perennial herb is an indicator of high-quality habitats. In the case of Loch Lomond this is ancient woodland (Botanical Society of Britain & Ireland, 2021).
<i>Pandion haliaetus</i>	<b>osprey</b>	<i>P. haliaetus</i> was lost as a breeding species in 1829 due to persecution. However, in 1990 it returned to Loch Lomond establishing the first breeding pair in over 150 years at the mouth of the river Endrick (Mitchell, 2001), with the species now widespread across Scotland (Forrester <i>et al.</i> 2007).
<i>Phylloscopus sibilatrix</i>	<b>wood warbler</b>	A summer visitor from sub-Saharan Africa, <i>P. sibilatrix</i> is associated with closed canopy oak-woods such as those found around Loch Lomond. <i>P. sibilatrix</i> is found locally across Scotland with a large population present around Loch Lomond (Bibby, 1989, Forrester <i>et al.</i> 2007) and increasing numbers of males singing in spring 2020 and 2021 (S. White, pers. obs.). This species, along with other oak-wood specialists such as common redstart <i>Phoenicurus phoenicurus</i> , pied flycatcher <i>Ficedula hypoleuca</i> and tree pipit <i>Anthus trivialis</i> , are all present around the loch in nationally significant numbers.
<i>Poecile montana</i>	<b>willow tit</b>	<i>P. montana</i> is on the U.K. Red List with a limited distribution in Scotland, with the species declining across its British range (Forrester <i>et al.</i> 2007). The only large Scottish population is in Dumfries and Galloway with it being extinct from south Lanarkshire since 2010, and just a few pairs remain in southern Ayrshire. However, surveys in 2016 on the islands in Loch Lomond and on the eastern side of the loch showed evidence of a small population (A. Wojciechowska & S. White, pers. comm.), which would represent the most northerly and isolated birds present in Scotland.
<i>Sitta europaea</i>	<b>wood nuthatch</b>	<i>S. europaea</i> is a recent entry on the Scottish species list, only breeding in the Borders for the first time in 1989, with the species now widespread and common across southern Scotland (Forrester <i>et al.</i> 2007). It first appeared in the environment of SCENE around 2016 (S. White, pers. obs.). The birds are now common around the loch and are breeding in the area.

<i>Physcomitrium sphaericum</i>	<b>dwarf bladder moss</b>	<i>P. sphaericum</i> is a small moss characterised by broad, pointed leaves found in only nine sites in the U.K., and listed rare throughout the rest of Europe (NatureScot, 2018). It is found on the edges of fluctuating ponds, such as Ward's Pond on Loch Lomond, where its small stature at 2-3mm makes it difficult to identify, often going years without a confirmed sighting (Mitchell, 2001).
<i>Elatine hydropiper</i>	<b>eight-stamened waterwort</b>	Lost to England in 1944, the species appeared in Scotland in 1968, and has since been discovered in multiple sites, including two on Loch Lomond (Idle <i>et al.</i> , 1970). It is generally intolerant of competition and occupies periodically inundated sandbars and mudflats where competition is low, allowing it to solely colonise an area. The wave action and regular water level fluctuation of Loch Lomond is key in maintaining the bare sand and mud habitat of the species, in part explaining its scarce occurrence. The plant is only visible when exposed in periods of low rainfall; this can be as little as 22 days per year (Idle <i>et al.</i> , 1970).
<i>Elatine hexandra</i>	<b>six-stamened waterwort</b>	Similar to <i>E. hydropiper</i> , <i>E. hexandra</i> thrives in areas subject to water level fluctuations as it is also intolerant of competition, with the exception of other annual species. In part, thriving in the habitat is due to it being unsuitable for larger rhizomatose perennial plants that are unable to establish on the destabilised soil, and due to its tolerance of harsh winter conditions. Although <i>E. hexandra</i> has been recorded historically throughout the Lomond catchment (in the 1960s), it is now limited to the edges of the Kilmannan reservoir where the rhythmic change in water level mimics favourable conditions (Idle <i>et al.</i> , 1970). It is regarded as nationally scarce (Online Atlas of the British and Irish Flora, 2021).
<i>Placynthium pannariellum</i>	<b>rare lacustrine lichens</b>	These specialised aquatic lichens have evolved to inhabit the low competition water-line habitats of large lochs in Scotland. Their hostile environment, combined with sporadic appearance, creates difficulties in studying them which may have resulted in under-recording, making Loch Lomond a nationally important site. Presently Scotland remains the stronghold of the species throughout the U.K. and the majority of its distribution is in the Lomond and Trossachs area (British Lichen Society, 2021). Their already, challenging environment is under increasing threat from hydropower development schemes causing rapid water level fluctuations that threaten to wipe out lichen communities.
<i>Porocyphus kenmorensis</i>		
<i>Dermatocarpon meiophyllizum</i>		
<i>Pilularia globulifera</i>	<b>pillwort</b>	<i>P. globulifera</i> can be found in many scattered sites throughout Britain, including the study area included in this paper, but is considered internationally threatened and has shown a decline in range across all of Europe. It inhabits ponds and seasonally fluctuating water bodies, typically on their margins, and often where livestock graze. Drainage schemes and water pollution, notably fertilisers, encourage the growth of coarse plants that outcompete <i>P. globulifera</i> causing their decline (Mitchell, 2001).

---

**Table 2.** Some species of importance in the national or international context, that are to be found in the study area.

## REFERENCES

- Adams, C., Brown, D., Little, S. & Tippett, R. (1990). A check-list of the freshwater invertebrate fauna of the Loch Lomond catchment. *The Glasgow Naturalist* 21, 537–554.
- Adams C.E. & Tippett, R. (1991). Powan, *Coregonus lavaretus* (L.), ova predation by newly introduced ruffe, *Gymnocephalus cernuus* (L.), in Loch Lomond, Scotland. *Aquaculture and Fisheries Management* 22, 239-246.  
<https://doi.org/10.1111/j.1365-2109.1991.tb00513.x>
- Air Pollution Information System. (2011). N deposition: River Jelly Lichen.  
<http://www.apis.ac.uk/node/1055> Accessed January 2022.
- Anonymous (1755). Accounts of the earthquake (Lisbon) upon Loch Lomond. *The Scots Magazine*, 593–594.
- Bibby, C.J. (1989). A survey of breeding Wood Warblers *Phylloscopus sibilatrix* in Britain, 1984–85. *Bird Study* 36, 56-72.  
<https://doi.org/10.1080/00063658909477003>
- Botanical Society for Britain and Ireland (2021). *Carex elongata*. <http://sppaccounts.bsbi.org/content/carex-elongata-0.html> Accessed January 2022.
- British Dragonfly Society (2021). Northern Emerald.  
<https://british-dragonflies.org.uk/species/northern-emerald/> Accessed January 2022.
- British Lichen Society (2021). *Placynthium pannariellum*.  
<https://www.britishlichensociety.org.uk/resources/species-accounts/placynthium-pannariellum> Accessed January 2022.
- Chrystal, G. (1910). Seiches and other oscillations of lake surfaces, observed by the Scottish Lake survey. In: Murray, L. & Pullar, J. (Editors). *Bathymetric Survey of the Scottish Freshwater Lochs*, pp. 29–90. Challenger Office, Edinburgh.
- Crotti, M., Adams, C., Etheridge, E., Bean, C.W., Gowans, A.R.D., Knudsen, R., Lyle, A.A., Maitland, P.S., Winfield, I.J., Elmer, K.R. & Praebel, K. (2020). Geographical hierarchical population genetic structuring in British European whitefish (*Coregonus lavaretus*) and its implications for conservation. *Conservation Genetics* 21, 927–939.  
<https://doi.org/10.1007/s10592-020-01298-y>
- Downie, R. & Weddle, R.B. (2005). The natural history of Loch Lomond and the Trossachs: conference proceedings. *The Glasgow Naturalist* 24(3), 1-55.
- Forel, F.A. (1886). *Le Lac Léman*. H. Georg, Bale.
- Forrester, R.W., Andrews I.J., McInerny, C.J., Murray, R.D., McGowan, R.Y., Zonfrillo, B., Betts, M.W., Jardine, D.C. & Grundy, D.S. (Editors) (2007). *The Birds of Scotland*. The Scottish Ornithologists' Club, Aberlady.
- Global Biodiversity Information Facility (2021) *Bithynia leachi*.  
<https://www.gbif.org/species/5778074> Accessed January 2022.
- Gray, J., & Smee, A. (1861). On the occurrence of the Loggerhead turtle in Scotland. *The Annals and Magazine of Natural History*. Series 3, 6, 351–352.  
<https://doi.org/10.1080/00222936108697430>
- Grieve, A. (1984). *A Modern Herbal*. Penguin, London.
- Hume, J.B., Recknagel, H., Bean, C.W., Adams, C.E. & Mable, B.K. (2018). RADseq and mate choice assays reveal unidirectional gene flow among three lamprey ecotypes despite weak assortative mating: Insights into the formation and stability of multiple ecotypes in sympatry. *Molecular Ecology* 27, 4572–4590.  
<https://doi.org/10.1111/mec.14881>
- Hunter, W.R. & Slack, H.D. (1958). *Pisidium conventus* Clessin in Loch Lomond. *Journal of Conchology* 24, 245-247.
- Idle, E.T. (1974). Botany. In: Tippett, R. (Editor). *A Natural History of Loch Lomond*, pp. 24–35. University of Glasgow Press, Glasgow.
- Idle, E.T., Mitchell, J. & Stirling A.M. (1970). *Elatine hydropiper* L. - new to Scotland. *Watsonia* 8, 45–46.
- James, M.C., Furness, R.W., Bowman, A.S., Forbes, K.J. & Gilbert, L. (2011). The importance of passerine birds as tick hosts and in the transmission of *Borrelia burgdorferi*, the agent of Lyme disease: A case study from Scotland. *Ibis* 153, 293–302.  
<https://doi.org/10.1111/j.1474-919X.2011.01111.x>
- Jerem, P., Herborn, K., McCafferty, D., McKeegan, D. & Nager, R. (2015). Thermal imaging to study stress non-invasively in unrestrained birds. *Journal of Visualized Experiments*, e53184.  
<https://doi.org/10.3791/53184>
- Kirk, C. (1903). Pomatorhine Skua at Loch Lomond. *The Annals of Scottish Natural History*, No. 45, 51.
- Leith, G.H. (1851). Occurrence of Bonaparte's Gull in Scotland. *Zoologist* 1851, 3117.
- Leslie, J. (1838). Climate. *Encyclopedia Britannica* 6, 749.
- Loch Lomond & The Trossachs National Park (2021). *Key Facts*. <https://www.lochlomond-trossachs.org/discover-the-park/key-facts/> Accessed January 2022.
- Lumsden, J. (1904). Letter re Ruby-Crowned Wren at Loch Lomond. *The Glasgow Herald* 7th January 1904.
- Lyle A.A., Stephen, A. & Adams, C.E. (2016). Establishment of conservation refuge populations for Scotland's rare freshwater fish, the powan *Coregonus lavaretus*. *The Glasgow Naturalist* 26(3), 3-9.
- Maitland, P.S. (1962). *Bathynella natans*, new to Scotland. *The Glasgow Naturalist* 18(4), 175–176.
- Maitland, P.S. (1966). *Studies on Loch Lomond II*. Blackie, Glasgow.
- Maitland, P.S. & Adams, C.E. (2005). The Aquatic Fauna of Loch Lomond and the Trossachs: What have we got; why is it important; how do we look after its future.  
[https://www.glasgownaturalhistory.org.uk/ll\\_papers/llproc\\_pmca.pdf](https://www.glasgownaturalhistory.org.uk/ll_papers/llproc_pmca.pdf) Accessed January 2022.
- Maitland, P.S., Adams, C.E. & Mitchell, J. (2001). The natural heritage of Loch Lomond: Its importance in a national and international context. *Scottish Geographical Journal* 116, 181–196.  
<https://doi.org/10.1080/00369220018737093>
- Maitland, P.S. & Hamilton, J.D. (1994). Glasgow University Field Station at Rossdhu, Loch Lomond:



- the first British University Freshwater Field Station. *Hydrobiologia* 290, ix–x.  
<https://doi.org/10.1007/BF00008945>
- Mammal Society (2020). Full Species List. <https://www.mammal.org.uk/species-hub/uk-mammal-list/> Accessed January 2022.
- Martin, C.H. (1907). Notes on some Oligochaeta found on the Scottish loch survey. *Proceedings of the Royal Society of Edinburgh* 28, 21–28.  
<https://doi.org/10.1017/S0370164600011536>
- Mitchell, J. (1974). Mammals. In: Tippet, R. (Editor). *A Natural History of Loch Lomond*. Glasgow University Press, Glasgow.
- Mitchell, J. (1983). The Ruby-Crowned Kinglet at Loch Lomond. A sift through the evidence relating to the almost forgotten 19th century record. *The Scottish Naturalist* 1983, 81–90.
- Mitchell, J. (1991). The Ruby-Crowned Kinglet on Loch Lomondside. *Loch Lomond Bird Report* 20, 15.
- Mitchell, J. (1994). The birds of the Endrick Mouth, Loch Lomond - an update of the annotated checklist up to 1st January, 1990. *The Scottish Naturalist* 106, 3–30.
- Mitchell, J. (2001). *Loch Lomondside*. Harper Collins, New York.
- Muir, A.P., Biek, R., Thomas, R. & Mable, B.K. (2014). Local adaptation with high gene flow: Temperature parameters drive adaptation to altitude in the common frog (*Rana temporaria*). *Molecular Ecology* 23, 561–574.  
<https://doi.org/10.1111/mec.12624>
- Murphy, K.J., Beverage, M.C.M. & Tippet, R. (1994). *The Ecology of Loch Lomond. Developments in Hydrobiology 101*. Kluwer, London.  
<https://doi.org/10.1007/978-94-011-0758-7>
- Murray, J. & Pullar, F.P. (1900). A bathymetrical survey of the fresh-water lochs of Scotland. Part I. The lochs of the Trossachs and Callander district. *The Geographical Journal* 15, 309–352.  
<https://doi.org/10.2307/1774954>
- Murray, J. & Pullar, L. (1910). *A Bathymetrical Survey of Scottish Lochs*. Challenger Office, Edinburgh.
- NatureScot (2018). *The story of Loch Lomond National Nature Reserve*.  
<https://www.nature.scot/sites/default/files/2018-02/The%20Story%20of%20Loch%20Lomond%20National%20Nature%20Reserve.pdf> Accessed January 2022.
- NatureScot (2021). Arctic Charr.  
<https://www.nature.scot/plants-animals-and-fungi/fish/freshwater-fish/arctic-charr#:~:text=In%20the%20British%20Isles%2C%20the,are%20occasionally%20found%20in%20rivers> Accessed January 2022.
- NBN Atlas (2021a). Downy Emerald.  
<https://species.nbnatlas.org/species/NBNSYS000005632> Accessed January 2022.
- NBN Atlas (2021b). Northern Emerald.  
<https://species.nbnatlas.org/species/NBNSYS000005635> Accessed January 2022.
- NBN Atlas (2021c). River Jelly-Lichen.  
<https://species.nbnatlas.org/species/NBNSYS0000018437> Accessed January 2022.
- Online Atlas of the British and Irish Flora (2021). *Elatine hexandra*.  
<https://www.brc.ac.uk/plantatlas/plant/elatine-hexandra> Accessed January 2022.
- Pollock, C.J., Capilla-Lasheras, P., McGill, R.A.R., Helm, B. & Dominoni, D.M. (2017). Integrated behavioural and stable isotope data reveal altered diet linked to low breeding success in urban-dwelling blue tits (*Cyanistes caeruleus*). *Scientific Reports* 7(5014), 1–14.  
<https://doi.org/10.1038/s41598-017-04575-y>
- Proudlove, G.S., Wood, P.J., Harding, P.T., Horne, D.J., Gledhill, T. & Knight, L.R.F.D. (2003). A review of the status and distribution of the subterranean aquatic Crustacea of Britain and Ireland. *Cave and Karst Science* 30, 53–74.
- Serban, E. (1973). Sur les Bathynellidae (Podophallocardia Bathynellacea) de l'Italie *Bathynella ruffoi* nov. sp. et *Bathynella lombardica* nov. sp. *Memorie del Museo Civico di Storia Naturale di Verona* 20, 17–37.
- Slack, H.D. (1957). *Studies on Loch Lomond I*. Blackie, Glasgow.
- Tippet, R. (1974). *A Natural History of Loch Lomond*. University of Glasgow Press, Glasgow.
- Vannote, R.L., Minshall, G.W., Cummins, K.W., Sedell, J.R. & Cushing, C.E. (1980). The river continuum concept (Vannote et al. 1980). *Canadian Journal of Fisheries and Aquatic Sciences* 37, 130–137.  
<https://doi.org/10.1139/f80-017>