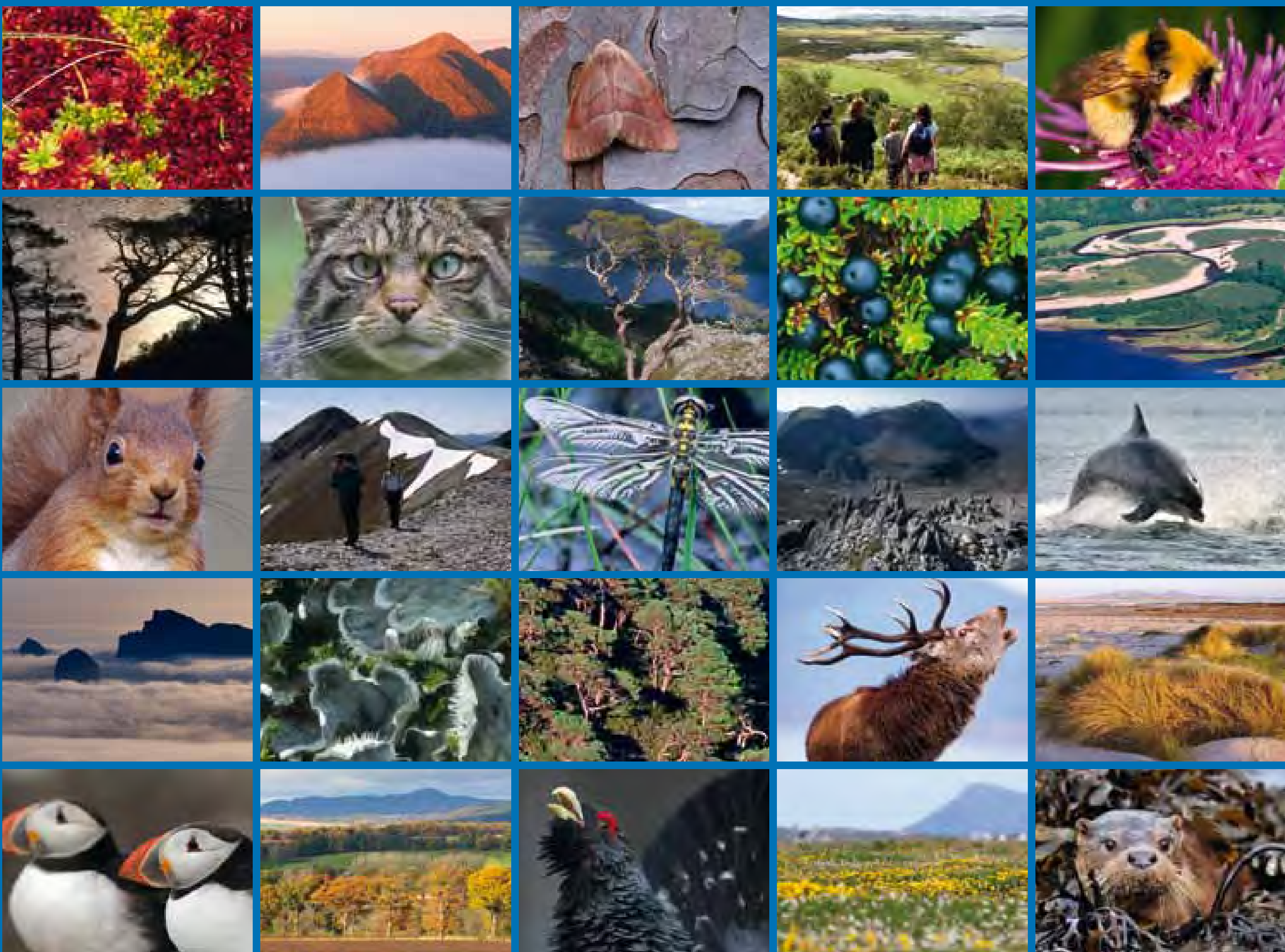
Scottish Natural Heritage
Commissioned Report No. 455

# The Scottish Beaver Trial: Monitoring and further baseline survey of the aquatic and semi-aquatic macrophytes of the lochs 2009



# COMMISSIONED REPORT

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# The Scottish Beaver Trial: Monitoring and further baseline survey of the aquatic and semi-aquatic macrophytes of the lochs 2009

For further information on this report please contact:

Mary Hennessy or Martin Gaywood
Scottish Natural Heritage
The Beta Centre, Innovation Park
University of Stirling
STIRLING
FK9 4NF
Telephone: 01786 435358
E-mail: mary.hennessy@snh.gov.uk

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COMMISSIONED REPORT

# Summary

## The Scottish Beaver Trial: Monitoring and further baseline survey of the aquatic and semi-aquatic macrophytes of the lochs 2009

**Commissioned Report No. 455 (iBids No. 7062)**
**Contractor: Centre for River Ecosystem Science, University of Stirling**
**Year of publication: 2011**

**BACKGROUND**

A five-year trial reintroduction of the European beaver commenced at Knapdale, Argyll, in spring 2009. An independent monitoring programme has been established that will consider the impacts of beavers on the aquatic vegetation of lochs within the Knapdale area. Several of these lochs form a feature of interest of the Taynish and Knapdale Woods Special Area of Conservation (SAC). An adequate baseline data set is required that establishes, in a repeatable and cost-effective manner, the condition of the vegetation in these lochs, in advance of the release of beavers. This monitoring will also yield data of suitable quality and resolution, to discriminate between a range of possible influences on lake vegetation, for the duration of the trial reintroduction.

This report discusses the results of applying the recommended survey protocol (used at eight primary lochs at Knapdale in 2008) to a further three lochs, which lie within the release area (but outside the SAC) and which appear to offer suitable habitat for beavers. None of the three water bodies has been used by beavers, so the data are considered to represent a baseline position. This report also reviews the first set of monitoring data acquired from repeat surveys of fixed transects established at eight primary lochs in 2008, and interprets interannual changes in the light of different potential sources of variability and observed effects of beavers on aquatic vegetation.

**MAIN FINDINGS**

- At the current time, the additional primary lochs support aquatic vegetation that is characteristic of oligotrophic waters where clarity is reduced due to the high humic content of the water. Several locally notable species, such as *Cladium mariscus*, are present in abundance. *Elodea canadensis* was found at one site and, given its known presence in two lochs surveyed in 2008, may be spreading slowly.
- Resurvey of a sub-sample of fixed quadrats appears to be an adequate method for detecting large-scale change in aquatic vegetation, without the need for re-mapping polygons. Temporal, spatial and surveyor-related factors are all sources of variation, but appear to be small alongside observed changes associated with beaver activity.
- The most significant impacts to date, of beavers on aquatic vegetation, are associated with water level rises caused by the construction of dams on loch outflows. These have produced several predictable changes in the richness and cover of plants in fixed quadrats. Such changes are likely to be reversible through the management of beaver dams. Effects associated with herbivory are less marked, but may cause local reductions

in the cover of preferred species. There is also evidence of indirect impacts, on isoetid plants, caused by uprooting of associated dominant emergent vegetation (e.g. *Schoenoplectus lacustris*), within which isoetids find shelter.

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*For further information on this project contact*:
**Mary Hennessy or Martin Gaywood**
**Tel:** 01786 435358
*For further information on the SNH Research & Technical Support Programme contact:*
DSU (Policy & Advice Directorate), Scottish Natural Heritage, Great Glen House, Inverness, IV3 8NW
Telephone 01463 725000 or email pads@snh.gov.uk

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*For further information on the monitoring of the Scottish Beaver Trial see:*
www.snh.gov.uk/scottishbeavertrial
or contact:
Martin Gaywood, Scottish Natural Heritage, Great Glen House, Inverness, IV3 8NW
**Telephone 01463 725230 or email beavers@snh.gov.uk**

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**Acknowledgements**

The methodology was drawn up in liaison with Mary Hennessy, Martin Gaywood, Megan Davies and Duncan Blake at SNH, who also provided comments on the draft reports. Valuable comments were also received from Max Wade.

This project was supported through a partnership of SNH and the Centre for River Ecosystem Science, University of Stirling, as part of the monitoring of the Scottish Beaver Trial. The authors wish to thank the Royal Zoological Society of Scotland (RZSS), the Scottish Wildlife Trust (SWT), and Forestry Commission Scotland for their help and cooperation. RZSS and SWT will also be contributing funds to the overall monitoring programme.

# 1 INTRODUCTION

In May 2008, the Scottish Government approved a licence for a 5-year trial reintroduction of the European beaver to Knapdale, Argyll. Three family groups, totalling 11 beavers, were released there in spring 2009. The primary aim of the trial is to study the ecology and biology of the European beaver in the Scottish environment, thereby allowing a measured assessment of the effect of beaver activity on the near-natural environment. Recorded effects will be judged against specific criteria. Evidence for positive contributions to ecosystem function and an absence of significant or unsustainable damage to ecosystems within the release site will be regarded as positive outcomes of the trial reintroduction. In relation to the features of the SAC, there must be no adverse effect on site integrity.

The trial is contingent on an independent monitoring programme. A range of factors will be monitored as part of the trial that will examine, amongst other things, the impacts of beavers on aquatic vegetation of lochs within the Knapdale area. For effective monitoring, the collection of baseline data that establishes the condition of loch vegetation prior to the influence of beaver activity is essential. Baseline data must be of sufficient quality and resolution to discriminate between the various possible future influences on lake vegetation. Observed changes in vegetation diversity will be interpreted in the context of environmental data provided by automated recording of water level fluctuations and regular measurement of chemical determinants of water quality (including key nutrients and chlorophyll), which will be carried out in all lochs for the duration of the trial.

Beavers have the potential to affect aquatic vegetation through a variety of direct and indirect mechanisms that operate over a range of spatial and temporal scales. Scales range from rapid but localised reductions in vegetation cover, resulting from preferential grazing of specific species (e.g. Fryxell & Doucet, 1993; Parker *et al.,* 2007), changes in light regime or physical habitat structure due to felling or caching activity (Naiman *et al.,* 1988; Jones *et al.,* 2009), through to larger scale changes in the type and distribution of vegetation due to changes in water level regime associated with damming (Pollock *et al.,* 2003). Although it is evident that beavers can modify the composition and biomass of herbaceous vegetation by direct herbivory, such effects are poorly researched; typically, impacts of beavers on herbaceous vegetation are attributed to indirect effects of habitat modification (Parker *et al.,* 2007).

In the present context, aquatic vegetation is of particular significance because the release sites are located within the Taynish and Knapdale Woods Special Area of Conservation (SAC). A qualifying feature of the site are the oligotrophic to mesotrophic standing waters with vegetation of the *Littorelletea uniflorae* and/or of the I*soeto-Nanojuncetea*, i.e. clear water lochs with aquatic vegetation and low to moderate nutrient levels. The underpinning SSSIs of the SAC, Taynish Woods SSSI and Knapdale Woods SSSI, are also designated for their standing water features. Consequently, assessment of the aquatic vegetation's response to the reintroduction of beavers is an important element of the trial. It is a condition of the licence that beaver dams on some standing water outflows within the SAC must be managed, to maintain baseline water level regimes. As a result, direct herbivory may be the more significant mechanism behind the effects that beavers have on aquatic vegetation at Knapdale.

Eight primary lochs and four secondary lochs were surveyed in 2008. Primary lochs are intended beaver release sites and those adjacent to them. Secondary lochs are a series of canal reservoirs situated on the edge of the release area and could potentially be utilised by wider-ranging beavers. The report on these surveys (Willby & Casas-Mulet, 2010) recommended the survey of aquatic and emergent vegetation in three additional primary lochs in the southern part of the Scottish Beaver Trial area, but outside the Taynish and Knapdale Woods SAC, as these lochs also appeared to provide suitable habitat for beavers and could be considered for the release of those individuals that remain in captivity. These additional primary lochs form the main subject of this report. They are described in Table 1 and their locations are shown in Figure 1 and Map 1 (Appendix 1).

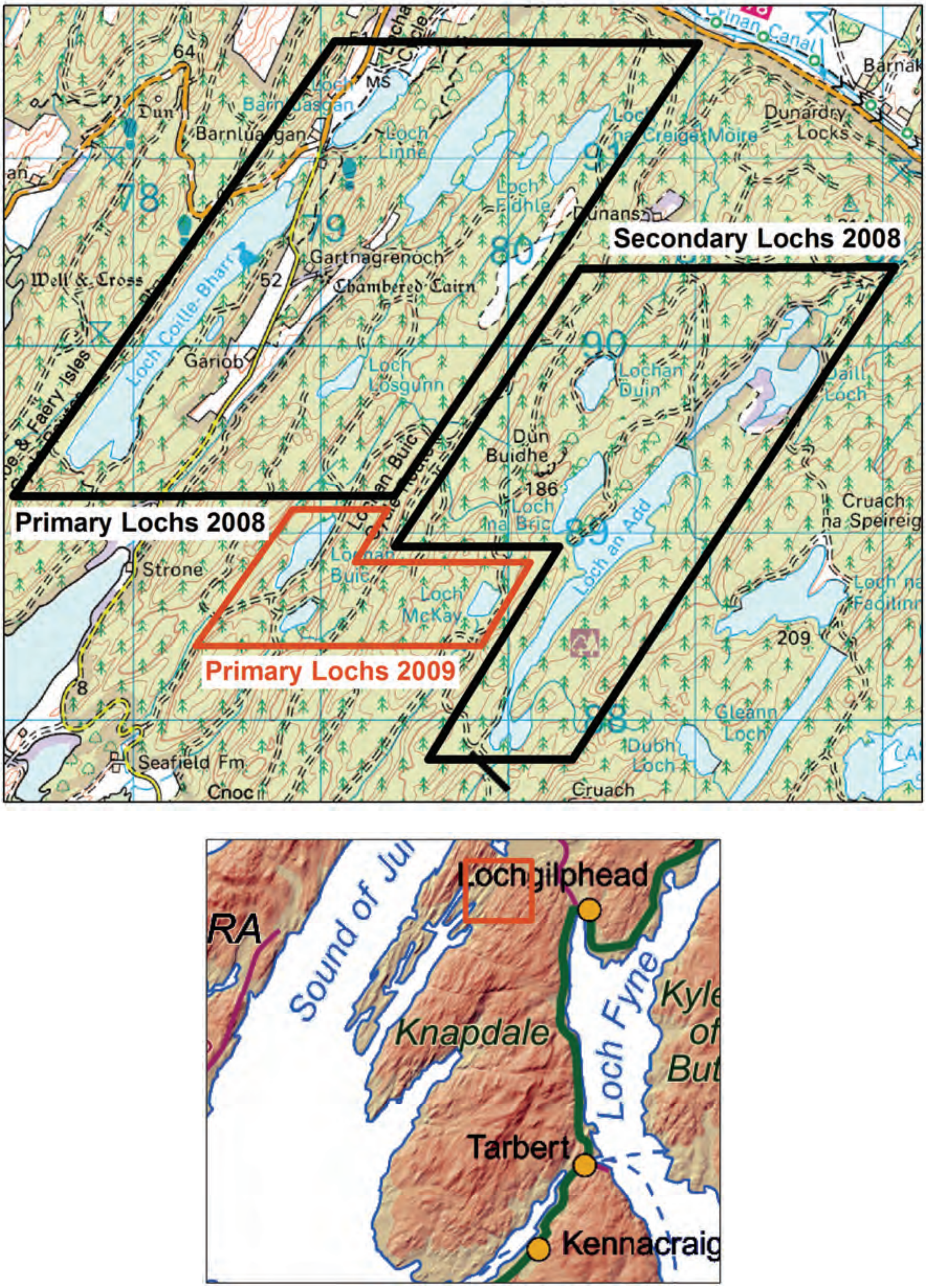


*Figure 1. Upper: location of primary lochs surveyed in 2008 (upper left panel), primary lochs surveyed in 2009 (lower left panel) and secondary lochs (lower right panel) at Knapdale. Lower: general geographical context. Inset shows area of enlargement. Reproduced from Ordnance Survey map data by permission of Ordnance Survey, © Crown copyright*

*Table 1. Characteristics of primary and secondary lochs at Knapdale.*

| Loch name | Grid reference | WBID[1] | Alkalinity (meq $L^{-1}$) | Altitude (m) | Area (ha) | Perimeter (km) | Max depth (m)[3] |
|---|---|---|---|---|---|---|---|
| **Primary Lochs** | | | | | | | |
| Dubh Loch | NR784902 | 25202 | ~0.50[4] | 38 | 0.4 | 0.3 | <5 |
| Creagmhor Loch[5] | NR803910 | 25160 | 0.20 | 68 | 5.2 | 1.1 | 10-15 |
| Loch Barnluasgan | NR792912 | 25144 | 0.59 | 43 | 5.3 | 1.2 | 10-15 |
| Loch Coille-Bharr | NR782901 | 25179 | 0.49 | 32 | 33.4 | 4.4 | 10-15 |
| Loch Fidhle[6] | NR799909 | | 0.21 | | | | 5-10 |
| Loch Linne | NR797910 | 25145 | 0.21 | 39 | 16.5 | 3.1 | 10-15 |
| Loch Losgunn | NR791898 | 25209 | 0.09 | 68 | 2.1 | 0.7 | 5-10 |
| Un-named loch (N)[7] | NR801910 | 25168 | 0.12 | 68 | 1.1 | 0.5 | <5 |
| **Additional primary lochs** | | | | | | | |
| Lochan Buic | NR789889 | 25242 | 0.28 | 49 | 3.9 | 1.1 | 5-10 |
| Loch McKay | NR798886 | 25264 | 0.39 | 142 | 1.9 | 0.6 | 5-10 |
| Un-named loch (S) | NR788885 | 25268 | 0.34 | 47 | 1.6 | 0.5 | 5-10 |
| **Secondary Lochs** | | | | | | | |
| Daill Loch | NR813899 | 25199 | 0.26 | 151 | 11.7 | 3.1 | 10-15 |
| Loch an Add | NR804887 | 25228 | 0.20 | 154 | 24.2 | 4.6 | 10-15 |
| Loch na Bric | NR803892 | 25229 | 0.87 | 152 | 5.2 | 1.1 | 10-15 |
| Lochan Duin | NR804898 | 25210 | 0.53 | 148 | 3.1 | 0.7 | 5-10 |

1 WBID = unique water body identifier code from the GB Lakes Inventory.
2 Alkalinity based on single samples collected in June 2002 and analysed by SEPA.
3 The maximum depths are based on modelled maxima as given in the GB Lakes Inventory, or estimated during field surveys. There is no measured bathymetry for any of these lochs and the true maximum depths probably exceed 15m in Coille-Bharr and Linne.
4 Alkalinity estimated from nearest adjacent lochs.
5 Note that there are various derivations of this name used on different Ordnance Survey sheets.
6 Note that because Loch Fidhle is contiguous with Loch Linne, it is not considered as a discrete water body by the GB lakes inventory.
7 Note that in the GB Lakes inventory this is erroneously labelled as Loch Fidhle.

## 2 BACKGROUND

In developing a survey protocol for the assessment of aquatic vegetation in eight primary lochs at Knapdale in 2008, Willby & Casas-Mulet (2010) considered the survey methods that had previously been applied to some of these lochs, for a variety of different purposes. These included the Scottish Loch Survey Project method (Lassière, 1998), the Site Condition Monitoring method (Gunn *et al.,* 2004) and the methods adopted by Murphy *et al.* (2002), for a previous baseline survey of the Knapdale Lochs in 2002. Criteria have been established to ensure that the output of monitoring provides for a fully informed outcome to the trial. It was argued that in order to address specific criteria regarding the degree and nature of damage, or enhancement, to natural ecosystem features, the primary considerations given to survey design should relate to:

1. the ability to detect change at different spatial scales, from localised to whole-lake effects and
2. the ability to discriminate between changes due to external factors and those attributable to beavers.

Refinements to previous survey methods, including those of Lassière (1998) and Murphy *et al.* (2002), were recommended for surveying the primary lochs, to address the above requirements. These refinements are summarised below.

1. Increase the number of fixed transects per loch from between 2 and 4 (Murphy *et al*., 2002) to 3 to 5. Three to 5 transects are considered adequate to characterise the vegetation of the lochs and to detect whole-lake change.
2. Quantify the submerged aquatic zone beyond the limits of beds of floating-leaved vegetation, by increasing the number of quadrats per transect from 3 (Murphy *et al.* (2002) to 4.
3. Ensure that quadrats include stands of preferred food species, especially where these are of limited extent within a loch (e.g. *Menyanthes trifoliata*).
4. Map vegetation polygons at higher spatial resolution by circumnavigating polygons in a boat and taking regular GPS readings to define the boundaries of each polygon.
5. Record maximum depths of colonisation by macrophytes in each loch.
6. Consider other attributes besides species composition (e.g. flower density), surveyed at a fixed time or times of the year.
7. Examine localised areas used for feeding by beavers.

The recommended method was implemented in the surveys of eight primary lochs in 2008.

Four additional secondary lochs (canal reservoirs outside the immediate release area) were also surveyed in 2008, because of their proximity to the primary lochs. As these lochs are not part of the SAC's feature of interest, are not beaver release sites, and are inaccessible in places, the methods recommended for surveys of these water bodies were less intensive than those for examining the primary lochs, but were consistent with the methods described by Lassière (1998) and those of Murphy *et al*. (2002) for secondary lochs. The periods during which surveys were undertaken are shown in Figure 2.

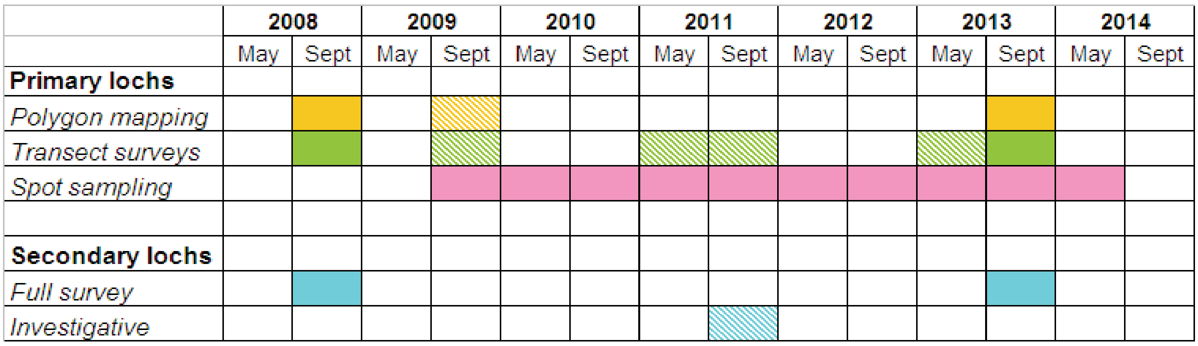


*Figure 2. GANTT chart showing past and future periods of survey. Each survey type is shown in a different colour. Hatched areas indicate periods when a subsample of sites have been or will be surveyed.*

With the possibility of future movements of beavers into neighbouring areas and the potential for new release sites outside the boundary of the SAC, it was considered circumspect to extend the monitoring to three additional lochs adjacent to the release area. Data collected from the additional lochs would enhance the baseline dataset. These lochs could be considered as candidate sites for the release of the beavers currently remaining in captivity. The water bodies concerned may therefore serve as reference sites or, if used by beavers, as potential sites for monitoring any impacts of beaver activity.

In addition to surveying new lochs, a sample of the fixed transects established in 2008 was resurveyed in 2009. Data collected from the water bodies actively used by the beavers provided an indication of any early effects on ecosystem attributes. Data from lochs being used by the beavers and from water bodies at which there was no evidence of beaver use were compared. Because the loch systems differ, and field variables are uncontrolled, it is not possible to treat the 'unused' lochs as control sites in the strictest sense. However, these lochs provide valid reference information on the natural variability that could be expected at release sites in the absence of beaver activity.

## 3 OBJECTIVES

The main objectives of this contract were to:

1. survey aquatic vegetation in three additional primary lochs using the protocol developed in 2008

2. re-survey a subsample of transects in each of the primary lochs considered in 2008, in order to assess inter-annual stability of vegetation, operator error, and potential effects of beavers on aquatic vegetation in those lochs where animals were released

3. suggest any possible improvements to the survey design and the feasibility of re-surveying fixed points that would improve cost-effectiveness or ability to detect impacts at different spatial scales

4. comment on any evidence to date of effects of beavers on aquatic vegetation at Knapdale.

## 4 METHODS

### 4.1 Baseline survey of additional primary lochs

The survey approach largely followed Lassière (1998) and Murphy *et al.* (2002). Periods during which surveys were undertaken are shown in Figure 2. Detailed vegetation mapping, supported by transect surveys, was undertaken only in the primary lochs.

The three additional primary lochs were surveyed by boat, thereby allowing all areas of the lochs to be surveyed in detail. A double-headed rake was used to sample fully submerged vegetation, both within visually assessed polygons and at points where water depth prevented visual assessment. In 2008, rake trawls revealed that submerged vegetation was not present at water depths greater than 6-7m in any of the lochs. In 2009, survey effort in additional lochs was therefore focused on shallower zones. When incident light conditions were favourable, a bathyscope or snorkel mask was used to view submerged vegetation *in situ*. The specific survey techniques applied at each loch varied, depending on boat access, the weather conditions at the time of survey, the morphometry of each loch, water clarity, and the structure of its vegetation. Low transparency due to the high humic content of the water was a constraint on underwater viewing at all sites. The survey approaches used are summarised on a loch-specific basis in Table 2.

*Table 2: Details of survey methods employed in 2008 and 2009 and conditions at time of survey*

| Loch name | Abbreviated name | Date surveyed[1] | Methods[2] | Survey conditions[3] |
|---|---|---|---|---|
| *Primary Lochs 2008* | | | | |
| Dubh Loch | Dubh | 24.09.09 | R,U | Good |
| Creagmhor Loch | Creagmho | 22.09.09 | B,R,U | Moderate |
| Loch Barnluasgan | Barnluas | 23.09.09 | B,R,U,S | Moderate |
| Loch Coille-Bharr | Coille B | 24.09.09 | B,R,U,S | Good-Moderate |
| Loch Fidhle | Fidhle | 23.09.09 | B,R,U,S | Moderate-Poor |
| Loch Linne | Linne | 23.09.09 | B,R,U,S | Moderate-Poor |
| Loch Losgunn | Losgunn | 24.09.09 | B,R,U | Moderate |
| Un-named loch (N) | Un-nam_N | 22.09.09 | B,R | Moderate |
| *Primary Lochs 2009* | | | | |
| Lochan Buic | Buic | 21.09.09 | B,R,U,S | Poor |
| Loch McKay | McKay | 22.09.09 | B,R,U | Good-Moderate |
| Un-named loch (S) | Un-nam_S | 22.09.09 | B,R,U | Moderate |

1. Dates for primary lochs 2008 refer to dates on which transects in these lochs were subsampled in 2009.
2. Survey methods employed, where B = boat; R = rake; U = underwater viewing *in situ*; S = snorkelling.
3. Good = still, strong incident overhead light; Moderate = light wind, cloud and angled light, occasional light showers; Poor = moderate wind, full cloud cover, intermittent heavy rain.

The process of mapping vegetation at each site involved the identification of macrophyte beds which were recorded as polygons, each characterised by the dominance of a particular species or combinations of species. The tendency of macrophytes to form large, comparatively discrete beds enabled edges to be mapped spatially with relatively little subjectivity. The number of polygons in each loch depended on the diversity and complexity of the vegetation, the number ranging from nine to 24. Each polygon was mapped by circumnavigating the macrophyte bed in the boat, taking GPS readings every 5-10m. GPS resolution at the time of recording was typically 6-10m. Plant composition (percentage cover for each species), water depth and substrate were recorded for each polygon. A total of 52 polygons were described and mapped across the three additional primary lochs. When overlain on digital aerial photographs taken in 2005, it was evident that this provided a very robust approach to vegetation mapping, there being a very close degree of match between polygons and coarse-scale vegetation features evident on the aerial photographs (Figure 2).

In the course of polygon mapping, representative locations were identified within each loch for a fixed-transect survey. At each location, a transect was established running perpendicular to the shore, from a point 2m inland to a depth of c3-5m, or the maximum depth of macrophyte colonisation if less. Five transect lines were established in Lochan Buic. In each of the smaller lochs, Loch McKay and the un-named loch (S), four transects were established. At each transect a 2m x 2m quadrat was located on the shore, typically 1-2m from the water's edge. The mid-point of the landward edge of this quadrat was marked with a length of Dexian railing driven into the soil, to a depth of c. 0.5m, leaving approximately 1m projecting above the surface. These markers are conspicuous and allow transect lines to be visually located from a distance, and ensure that they are avoided by other fieldworkers. Three further quadrats of the same size were positioned along the transect, one at the water's edge in the marginal zone, a second at a water depth of between 0.5m and 1m and the third at the end of the transect, near the limit of the vegetated littoral zone. The mid-point of each of the four 2m x 2m quadrats was recorded with a hand-held GPS. Water depth and substrate were noted and the percentage cover of all plants present in each quadrat was estimated visually, to the nearest 5%. Quadrats located in shallow water (<0.5m) were clearly viewable from a standing position. In deeper water, quadrats were generally viewed from the boat, using a snorkel-mask as required. To avoid disturbing the vegetation along transects, a rake was not used. At several sites, snorkelling was undertaken along transects to confirm the cover of individual species if the water was deeper than 1.5m and the bed was not clearly visible from the surface, or if *in situ* viewing of submerged vegetation indicated that snorkelling was the most appropriate method, due to the density or complexity of the vegetation. The setup and survey of transects and quadrats followed the approach adopted in 2008 at the eight existing primary lochs. A subsample of the transects established on each of the three additional primary lochs will be re-surveyed in May and September 2011.

On completion of the polygon mapping and transect surveys, an overall assessment of the abundance of taxa in each water body was made and agreed by two observers, using the DAFOR scoring system, as described by Lassière (1998), as the basis for describing abundance (Dominant = D; Abundant = A; Frequent = F; Occasional = O; Rare = R). In line with previous surveys, DAFOR values were prefixed with 'L' for 'locally' to signify a concentration of a taxon at a particular abundance, rather than a general distribution throughout the water body. Plants which could not be identified in the field were retained and identified subsequently using Stewart & Church (1992), Preston (1995), or Rich & Jermy (1998). At each loch, the Secchi depth and maximum depth colonised by macrophytes were also noted, as these variables may have value as indicators of future change in aquatic plant abundance.

The results were compared with those of the surveys of primary lochs in 2008, in terms of plant composition. Comparisons were also made between the results of the 2009 survey and a survey of Loch McKay carried out in 1989. There were no previous surveys of Lochan Buic and the un-named loch (S). Comparisons were made by assessing summary metrics for each water body, such as the number of aquatic plant taxa recorded, or using the Lake Macrophyte Nutrient Index (LMNI). This is an index of lake plant nutrient affinity developed for use in the assessment of aquatic vegetation and forms the basis of the UK's Water Framework Directive classification tool for assessing lake ecological status based on macrophytes (Willby *et al.,* 2009). The LMNI ranks taxa, in order of increasing nutrient affinity, on a scale of 1-10, and is converted to a score for a site, based here on the average of the ranks of the taxa present weighted by the cover of each taxon.

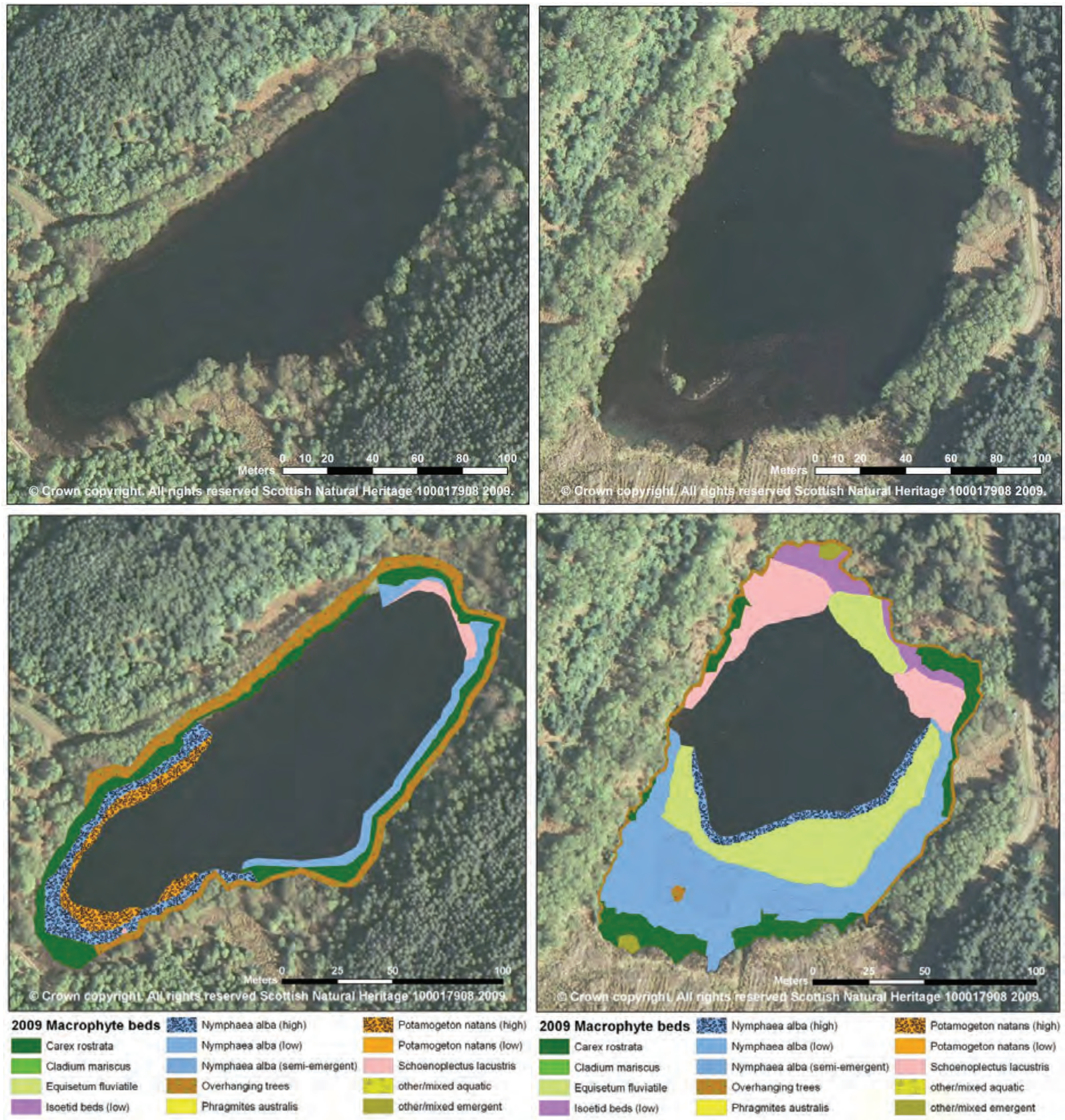


*Figure 1. Relationship between aerial photography (2005) and GPS mapped polygons of vegetation as shown in GIS for two of the additional primary lochs surveyed in 2009 (left, Un-Named Loch (S); right, Loch McKay)*

## 4.2 Re-surveys of fixed transects in 2008 primary lochs

In each of the eight primary lochs surveyed in 2008, three transects were selected for subsampling. All four quadrats distributed on each transect were then surveyed according to the same protocol used in 2008, with the cover of each species present assessed visually to the nearest 5%. Since the markers used were conspicuous, it was straightforward to relocate the landward end of each transect line. Thereafter, quadrats were relocated using a combination of GPS, photographs and previous floristic data. It should be noted that complete overlap of quadrats at the second, third and fourth positions on the transect line during repeat sampling is impossible to achieve. It is more likely that the average overlap of these quadrats is approximately 50%. However, all aquatic quadrats were located within large areas of homogeneous vegetation, so a small variation in location between years is probably of little consequence and will certainly be adequate for quantification of larger-scale impacts, or pronounced local herbivory.

# 5 RESULTS

## 5.1 Surveys of additional primary lochs

Detailed descriptions of the three additional primary lochs are given below. Each loch is also represented by a vegetation map showing individually numbered polygons identified during the 2009 survey (Appendix 1). Polygons are available in ArcGIS. Clicking on these polygons in ArcGIS will bring up a list of their constituent plant species, plus depth and substrate characteristics. Separate ArcGIS shape files have been constructed for polygons, individual sampling points (where independent of polygons), transect points and photo locations. In preparing the GIS files, it was noted that the loch shoreline shape files supplied can sometimes only be considered to provide a rough approximation of the true loch shoreline when overlain on geo-rectified aerial photographs. Thus, a certain amount of mismatch between the vegetation polygons and the Ordnance Survey mapped shoreline is to be expected.

Polygon information, a summary of the data collected at the fixed transects at each site and co-ordinates of all polygons, points, transect quadrats and photographs have been submitted to SNH in tabular and digital formats. A separate photo-library to accompany this report has also been submitted to SNH.

To ease the mapping of polygons in GIS and to assist the rapid interpretation of vegetation maps the 52 individually delimited polygons have been classified manually into different polygon types that follow the typology applied in 2008. One additional polygon type was created to deal with semi-emergent stands of *Nymphaea alba*. These types are described in Table 3.

## 5.2 General description of primary lochs including additional water bodies

The water bodies of Knapdale represent a complex of lakes that are typically elongate in shape and orientated south-west north-east, following the direction of the local geology. The lochs are comparatively small (2-35 ha), yet some are surprisingly deep (approximately 15m) relative to their area (Table 1). Shoreline complexity is low, the sides of most lochs being rather steep and rocky with shallow, well-vegetated areas being confined to the apices of the larger sites. The lochs are of low to moderate base status (alkalinity 0.1-0.54 meq $L^{-1}$) and nutrient concentrations are consistently low (summer TP <10µg P $L^{-1}$) reflecting the extensive catchment afforestation (both native and plantation) and lack of point sources of nutrients. Water transparency is comparatively low (Secchi depths typically 1-2m), due to the relatively high humic content of the water, especially in the more base-poor sites. Drainage basins are small, and in all cases each loch occupies a large proportion (20-30%) of its catchment area. Accordingly, water level fluctuations are relatively constrained, the mean annual water level range across the primary lochs lying between approximately 0.5-0.8m.

The aquatic vegetation is characterised principally by two floating-leaved species, *Nymphaea alba* and *Potamogeton natans*, which extend to water depths of 3m and occur at all sites. The abundance of these two species is consistent with the humic coloration of the water at most sites. These species are widely underlain by, or, in shallow water with coarse substrates, replaced by the isoetids *Littorella uniflora* and *Lobelia dortmanna*. In similar situations on peat, *Juncus bulbosus* is widespread and often locally abundant. The dominant floating-leaved vegetation is interspersed at some sites with other floating-leaved species, such as *Nuphar pumila* and *Sparganium angustifolium*. In sheltered areas of deeper water (3-6m) a range of broad-leaved pondweed species form large beds at several sites, sometimes intermixed with *Myriophyllum alterniflorum*. These species include *Potamogeton lucens*, *P. praelongus*, *P. perfoliatus* and *P.gramineus x lucens (P. x angustifolius, formerly*

*P. x zizii)*. Charophytes, notably *Chara virgata* and *Nitella translucens*, are frequent to abundant in a number of water bodies. Due to the combination of steep shoreline gradient and coarse substrate around most sites, emergent vegetation is comparatively restricted, but reasonably extensive beds of *Cladium mariscus, Phragmites australis* and *Carex rostrata* occur in several lochs. More commonly, there is rather open dispersed growth of *Phragmites australis*, *Scheonoplectus lacustris* and *Equisetum fluviatile*, which overlaps with the beds of floating-leaved species. Figure 4 summarises the variation in composition of aquatic vegetation, in all of the primary and secondary lochs, using a Detrended Correspondence Analysis ordination. Despite the similarity of sites and their catchments, and the proximity of sites to one another, it is clear that there is a fairly high turnover of species between sites, with only *Potamogeton natans* and *Nymphaea alba* being almost universal. The arrangement of sites along axis 1 (Figure 4) reveals a general trend from small peaty sites on the left to larger clear water sites on the right.

Woody vegetation partially or fully encircles most lochs, forming a canopy over the inner-most 2-4 m of the littoral zone. It is dominated by birch *Betula pubescens*, with alder *Alnus glutinosa*, several *Salix* species, rowan *Sorbus aucuparia* and hazel *Corylus avellana* all well represented locally. In drier areas, the woodland under-story is dominated by *Pteridium aquilinum*, *Calluna vulgaris* and *Vaccinium myrtilus*, while acid mire forming species, such as *Molinia caerulea*, *Myrica gale*, *Sphagnum* spp. and several *Juncus* species dominate in the wetter areas. The catchments of all sites, up to 20m from the water's edge, have been subject to extensive post-war planting with conifers.

Observations on the composition and distribution of vegetation at specific lochs are provided below. A representative photograph is included in the account for each lake, showing a variety of features to which the text refers. These plates are collated at the end of the report (Section 8). An overview of the submerged and floating-leaved vegetation at all sites, based on DAFOR scores, can be found in Table 4. This integrates the 2009 surveys with the data obtained in 2008 for other primary lochs. The composition of the emergent vegetation at all sites is summarised in Table 5. Table 6 includes information on the number of taxa and the Lake Macrophyte Nutrient Index value for previous surveys of each water body. These have been calculated for comparative purposes. The LMNI values of the additional primary lochs lie well inside the range presented by the 2008 lochs (4.92 ± 0.57). Similarly, the species richness of the additional lochs is in line with the values recorded in 2008 (mean 10 ± 4.6 species per loch).

*Table 3: Composition of vegetation in characteristic polygon types in additional primary lochs, as surveyed in 2009*

| Polygon name | Frequency | Description |
|---|---|---|
| *Carex rostrata* | 9 | stands dominated by *Carex rostrata* in which other species (e.g. *Littorella*, *Juncus bulbosus*, *Juncus articulatus*) may occur as subordinates |
| *Cladium mariscus* | 4 | stands dominated by *Cladium mariscus* with occasional very limited cover of other species (e.g. *Equisetum fluviatile*, *Nymphaea alba*) |
| *Equisteum fluviatile* | 4 | open stands dominated by *Equisetum fluviatile* sometimes with associated *N. alba*, *Schoenoplectus lacustris* or *Potamogeton natans* |
| Isoetid beds (low) | 3 | stands with <50% cover of *L. uniflora* and/or *L. dortmanna*, either intermixed with small emergents such as *C. rostrata* and *J. articulatus*, or overlain by *N. alba* |
| *Nymphaea alba* (high) | 4 | stands with >50% cover of N. alba with limited cover of associates, most commonly *P. natans*, *S. lacustris* or *E. fluviatile* |
| *Nymphaea alba* (low) | 5 | stands with <50% cover of *N. alba* intermixed with low density *P. natans, C. rostrata*, *E. fluviatile* or *S lacustris*. Often underlain by low density of *L. uniflora* or *L. dortmanna* |
| *Nymphaea alba* (semi-emergent) | 2 | Stands of low density *N. alba* on partially exposed peat, usually with very low density of *C. rostrata*, plus a large number of emergent and marginal species at negligible cover. |
| Other/mixed aquatic | 2 | stands dominated by species with very low overall frequency (e.g. *Nuphar pumila*, *Eleogiton fluitans*, *Potamogeton polygonifolius*) or mixed stands with no clear dominant, but usually including *Myriophyllum alterniflorum*, *J. bulbosus*, *L. uniflora*, *S. lacustris* or *Elodea canadensis* |
| Other/mixed emergent | 2 | stands dominated by species with very low overall frequency (e.g. *Eleocharis multicaulis*, *Phalaris arundinacea* or *Carex paniculata*) or mixed stands with no clear dominant, but usually including *S. lacustris*, *Phragmites australis*, *E. fluviatile* and/or *C. rostrata* plus a low density of *N. alba*) |
| Overhanging trees | 4 | range of fringing woody vegetation type in which *Betula pubescens* usually dominant or co-dominant |
| *Phragmites australis* | 7 | stands with cover dominated by *P. australis*, with *P. natans*, *L. uniflora* or *E. fluviatile* the most common associates |
| *Potamogeton natans* (high) | 1 | stands with >50% cover of *P. natans*, occasionally with sparse cover of *N. alba* |
| *Potamogeton natans* (low) | 1 | stands with <50% cover of *P. natans*, typically associated with sparse cover of *N. alba* and *S. lacustris* |
| *Schoenoplectus lacustris* | 4 | stands dominated by *S. lacustris* with occasional cover of *E. fluviatile* or *N. alba* |

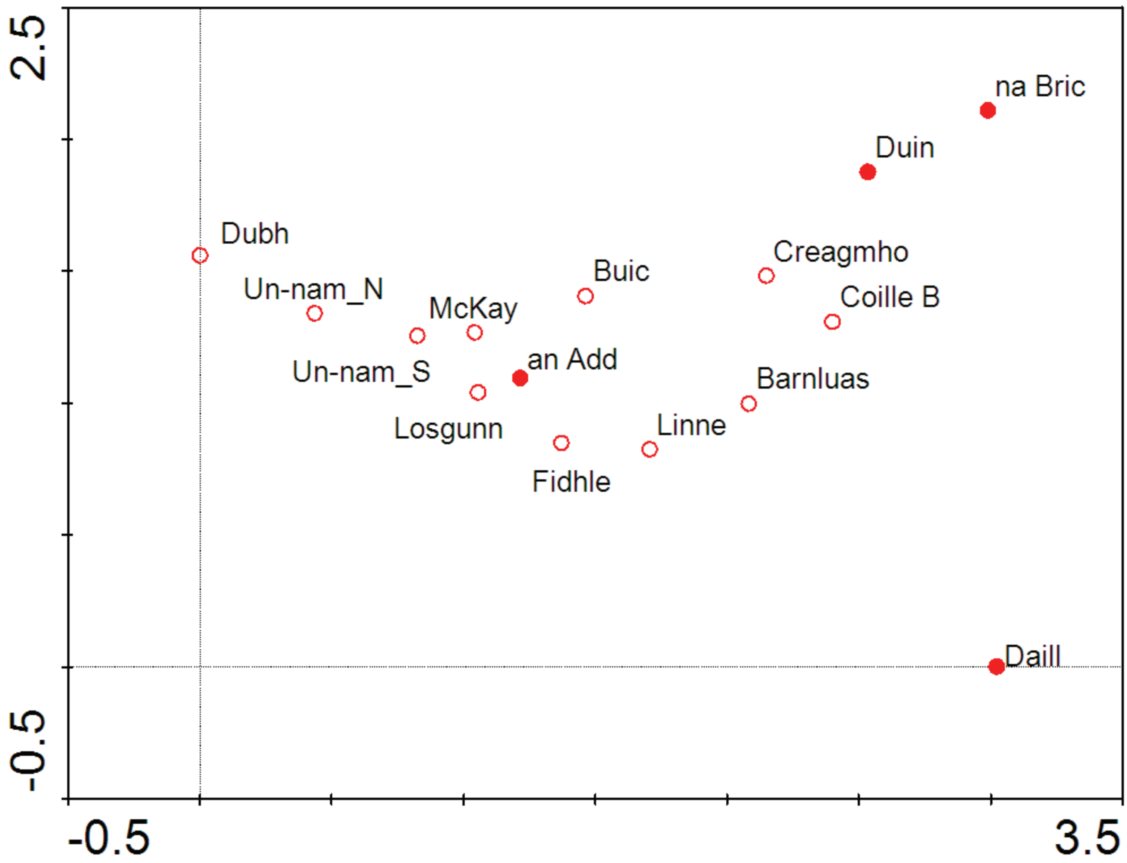


*Figure 4. Ordination plot using Detrended Correspondence Analysis of vegetation composition data for the primary and secondary lochs surveyed in 2008-9. Sites are distributed across both axes in terms of compositional similarity. A gradient of size and peatiness of the lochs visibly correlates with Axis 1, with small peaty lochs to the left and large clear lochs to the right. The four secondary lochs are shown as filled dots (na Bric = Lachan na Bric; Duin = Loch Duin; an Add= Loch an Add; Daill = Loch Daill). A key to the abbreviation of names for Primary Lochs can be found in Table 2.*

### 5.3 Lochan Buic

This is a relatively shallow and sheltered loch, with few areas of coarser substrate. The aquatic vegetation is dominated by *Nymphaea alba*. *Potamogeton natans* occurs locally but is more restrained than in most other primary lochs. There are several large beds of mixed isoetids. However, the most striking feature of the aquatic vegetation at Lochan Buic is the remarkable abundance of *Eleogiton fluitans*, a species normally confined to smaller and very shallow water bodies. Thus, while *E. fluitans* occurs elsewhere in such habitats in the Knapdale-Taynish area, it has not been recorded in any other primary or secondary loch. *Elodea canadensis* was also found to be locally abundant although not widespread. Elsewhere this species occurs only in Lochs Barnluasgan and Coille Bharr. There is a boat and moorings at Lochan Buic and there is access for fishing, so transfer by anglers may have been the means of spread. One drifting fragment of *Potamogeton perfoliatus* was found, but no rooted beds of this species. This was likely to be due to the very poor weather conditions during the survey, rather than absence of a population of the species. Since the other lochs at Knapdale that support *P. perfoliatus* also all support other submerged pondweeds (Table 4) there is the possibility that a bed of another species, such as *P. praelongus* or *P. x angustifolius*, was overlooked during the survey of Lochan Buic. See Appendix 1: Map 2.

The major feature of the emergent vegetation at Lochan Buic is the relatively open-structured growth of *Phragmites australis*, which almost encircles the loch. There are also several large stands of *Equisetum fluviatile*, and scattered, smaller stands of *Cladium mariscus*. The emergent vegetation is particularly abundant at the northern apex of the loch. Unusually, *Schoenoplectus lacustris* is absent.

Lochan Buic is surrounded by mixed *Betula*-dominated riparian woodland which includes extensive willow near the water's edge. The understorey is composed of typical mixed heath and acid mire species with both *Molinia caerulea* and *Myrica gale* being common. Woodland development is constrained by the presence of an access track running along the eastern shore.

There are no previous records of aquatic plants specific to this loch with the exception of *Cladium mariscus* which was recorded there in 1970.

### 5.4 Loch McKay

This is a small and apparently relatively shallow loch. Although there are areas of gravel at the north end in the vicinity of the inflow, peaty substrates dominate. Several factors, discussed below, appear to have had a significant impact on the vegetation at this site in recent years. In terms of aquatic vegetation, there is the typical combination of *Nymphaea alba* and *Potamotegon natans,* with the former occurring partly as semi-emergent stands around the southern part of the loch, a phenomenon also seen in the 2008 surveys of Loch Losgunn and unnamed loch (N). However, the major feature of Loch McKay is the exceptional abundance of *Chara virgata* which forms an almost continuous sward over much of the substrate of the water body, being replaced locally by *Nitella translucens*. The other notable feature is several large beds of *Littorella uniflora* and *Lobelia dortmanna* in shallow water on gravels at the north end of the site.

The emergent vegetation is dominated by several very large beds of *Equisetum fluviatile* and *Schoenoplectus lacustris*. The current extent and distribution of these species is suggestive of major water level change during the last few decades, although the current water levels appear to be stable. In more marginal areas *Carex rostrata* is also common.

The south end of Loch McKay is un-wooded and has typical mire vegetation. Otherwise the loch is surrounded by mixed *Betula*-dominated woodland in which *Salix*, *Alnus* and *Sorbus* are all locally common. Planted Sitka spruce is common along parts of the shore.

Comparison of the results of the present survey with those of the 1989 NCC Scottish Loch Survey Project reveals that there have been some marked changes in the vegetation of this loch in the last 20 years (Table 4). The LMNI score and number of taxa present are virtually unchanged. However, while the composition of the emergent vegetation appears to be stable (Table 5), large differences have been noted in the aquatic vegetation that cannot simply be attributed to timing or surveyor error. In 1989, Loch McKay contained several pondweed species, including *P. alpinus*, *P. perfoliatus* and *P. praelongus*, along with frequent *Nuphar pumila*, none of which could be found in the present survey, even though it was conducted under reasonably favourable viewing conditions.

This loch has a very small upstream catchment and appears to be fed by a diversion from a small stream to the north of the site. It is possible that reservoir operation in the nearby Loch an Add will influence whether this stream is running. The loch is also managed for fishery purposes, although it is unclear what form this management takes. However, it does not appear to be stocked with fish at the present time. The site is signed as being in the ownership of the Lochgilphead and District Angling Association and is surrounded by a partially submerged post and wire fence. The design of this fence is such that it could only have been erected when water levels were approximately 0.5m lower than at the present time. Presumably this would have required several years of drought or temporary shutting off of the inflow to allow the site to draw down naturally. There is also evidence that the catchment to the south has been moor-gripped for tree planting, perhaps 5-10 years ago, although trees have never been planted. This is likely to have increased sediment input to the loch and may have contributed to the development of semi-emergent beds of *Nymphaea* at the north end of the site. The current shape and area of Loch McKay match those shown on the 1873 OS sheet for Argyll suggesting that any major disturbance has occurred recently, but not in the last few years. The marked abundance of stoneworts is also suggestive of recent past disturbance.

### 5.5 Un-named loch (S)

This is a small, sheltered and fairly shallow loch that lies adjacent to Lochan Buic. Peat substrates dominate. The vegetation is typical of the smaller Knapdale lochs, being dominated by *Nymphaea alba* and *Potamogeton natans*. Both species form large dense beds in the westerly part of the loch. The only really notable feature of the aquatic vegetation is several very small patches of *Nuphar pumila*.

In terms of emergent vegetation, the site is virtually surrounded by *Carex rostrata*, while there is one large bed of *Schoenoplectus lacustris* at the north-east end. *Equisetum fluviatile* is widely distributed. This vegetation, combined with the almost continuous beds of *Nymphaea alba,* gives the overall impression of a well-developed hydrosere that is reminiscent of Dubh Loch.

As at Lochan Buic, this site is surrounded by mixed *Betula*-dominated riparian woodland with an extensive area of willow near the water's edge. The understorey is composed of typical mixed heath and acid mire species, with both *Molinia caerulea* and *Myrica gale* being common.

This site appears to be little disturbed, although there is a short board walk that gives access around the westerly end of the loch.

There are no previous records of aquatic plants specific to this loch.

*Table 4. Summary of aquatic vegetation composition at primary lochs in Knapdale 2008/9*

| | | **Barnluasgan** | **Coille-Bharr** | **Creagmhor** | **Dubh** | **Fidhle** | **Linne** | **Losgunn** | **Un-named (N)** | **Lochan Buic** | **McKay** | | **Un-named (S)** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Taxa | sp_LMNI | 09/09/2008 | 12/09/2008 | 11/09/2008 | 11/09/2008 | 10/09/2008 | 10/09/2008 | 01/10/2008 | 11/09/2008 | 21/09/2009 | 26/06/1989 | 22/09/2009 | 22/09/2009 |
| *Callitriche stagnalis* | 5.98 | R | | | | | | | | | | R | |
| *Chara virgata* | 5.55 | R | LA | | | | | | | O | | D | LF |
| *Eleogiton fluitans* | 3.45 | | | | | | | | | LA | | | |
| *Elodea canadensis* | 7.14 | LA | LA | | | | | | | LF | | | |
| Filamentous algae | 6.39 | LF | | | | | | | | | | | |
| *Fontinalis antipyretica* | 5.42 | O | | | | | O | | | | | | |
| *Isoetes lacustris* | 3.09 | R | LF | LF | | | R | | | O | | | |
| *Juncus bulbosus* | 3.72 | | | LF | | LF | R | LA | R | F | | O | LA |
| *Lemna minor* | 7.58 | | | | O | | | | | | | | |
| *Littorella uniflora* | 4.70 | O | A | LF | | F | A | LF | | O | F | LF | |
| *Lobelia dortmanna* | 2.46 | R | LF | LF | | R | A | LF | | F | A | LF | |
| *Myriophyllum alterniflorum* | 4.54 | | LA | O | | O | LF | | | R | F | | |
| *Nitella opaca/flexilis* | 5.60 | | | R | | | | | | | F | | |
| *Nitella translucens* | 5.17 | | | | | | | O | | LF | | LA | O |
| *Nuphar lutea* | 6.92 | | | | | LF | | | | | | | |
| *Nuphar pumila* | 5.33 | R | | | | LF | | O | | | F | | R |
| *Nuphar x spenneriana* | 5.61 | | | | | | | | | | | | |
| *Nymphaea alba* | 5.54 | A | LA | F | F | A | LA | LA | LA | A | A | LA | A |
| *Poatmogeton alpinus* | 5.79 | | LF | | | | | | | | R | | |
| *Potamogeton berchtoldii* | 6.07 | O | O | O | | | | | | | | | |
| *Potamogeton gramineus* | 5.51 | | | | | | | | | | | | |
| *Potamogeton lucens* | 7.02 | LF | LF | | | | | | | | | | |
| *Potamogeton natans* | 5.16 | A | F | O | A | A | LA | A | A | LA | F | F | A |
| *Potamogeton obtusifolius* | 6.72 | | R | | | | | | | | | | |
| *Potamogeton perfoliatus* | 5.83 | | LF | R | | | | | | R | F | | |
| *Potamogeton polygonifolius* | 3.50 | | | | | LF | O | LA | O | | | LF | O |
| *Potamogeton praelongus* | 5.77 | LA | LF | | | | | | | | R | | |
| *Potamogeton x zizzii* | 5.69 | | LF | LF | | | | | | | | | |
| *Sparganium angustifolium* | 3.65 | LF | LF | | | R | O | F | | O | F | R | R |
| *Sparganium natans* | 4.84 | | | | | | | | | | | | |
| *Utricularia intermedia* | 2.19 | | | | | R | R | | | | | | |

Sp LMNI refers to the rank of each species on a continuous scale from 1-10 based on nutrient affinity where 10 indicates affinity for the most fertile environments. Shaded cells highlight major discrepancies between the surveys of Loch McKay in 1989 and 2009. R=rare, O=occasional, F=frequent, A=abundant, D=dominant, and a pre-fix of L=locally.

*Table 5. Comparison of emergent plant composition at primary lochs in 2008/9*

| | Barnluasgan | Coille-Bharr | Creagmhor | Dubh | Fidhle | Linne | Losgunn | Un-named (N) | Lochan Buic | McKay 1989 | McKay 2009 | Un-named (S) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Caltha palustris* | R | | R | | | | | | | | | |
| *Carex lasiocarpa* | | | | | LF | LF | | | | | | |
| *Carex nigra* | | | | | | | | | O | F | O | |
| *Carex paniculata* | | | | LA | | | (R) | | | | | |
| *Carex rostrata* | F | F | | LF | F | F | F | LF | LF | A | F | A |
| *Cladium mariscus* | | | LA | LA | LA | LA | | | LA | | | |
| *Eleocharis multicaulis* | | | O | | O | O | LF | | | | O | LF |
| *Eleocharis palustris* | O | LF | R | R | R | O | | | R | O | O | O |
| *Equisetum fluviatile* | F | F | O | A | O | F | | O | F | A | A | F |
| *Glyceria fluitans* | | | | | | | | | | | | R |
| *Hippuris vulgaris* | | | | | | | | | | F | | |
| *Hydrocotyle vulgaris* | R | | | O | R | R | | | | O | O | O |
| *Iris pseudacorus* | R | O | | | | | | | | R | R | O |
| *Juncus acutiflorus* | O | | O | | LF | O | R | | | | LF | F |
| *Juncus articulatus* | | R | R | | O | R | LF | R | R | A | | LF |
| *Juncus effusus* | R | R | | | | R | R | | | O | | |
| *Lythrum salicaria* | R | O | | | | | | | | | | |
| *Mentha aquatica* | R | R | | LF | | | | | | | | |
| *Menyanthes trifoliata* | LF | R | | LF | O | O | | R | | R | R | |
| *Oenanthe crocata* | | O | | | | | | | | | | |
| *Phalaris arundinacea* | | LF | | | | R | | | | | | |
| *Phragmites australis* | LA | LA | LF | | | | O | O | A | | | |
| *Potentilla palustris* | O | R | | | | | | | R | | R | O |
| *Ranunculus flammula* | R | | | | R | R | | | | O | O | |
| *Schoenoplectus lacustris* | LA | LF | LA | | LF | LF | | | | A | LA | F |
| *Scutellaria galericulata* | | O | | | | | | | | | | |
| *Sparganium erectum* | | R | | | R | | | | | R | | |
| *Sphagnum* | | | | O | | | | | | P | | |
| *Veronica scutellata* | | | | | R | | | | | | | |

R=rare, O=occasional, F=frequent, A=abundant, D=dominant, and a pre-fix of L=locally.

*Table 6. Summary metrics for aquatic vegetation in primary lochs at Knapdale 2008/9*

| | **Barnluasgan** | **Coille Bharr** | **Creagmhor** | **Dubh** | **Fidhle** | **Linne** | **Losgunn** | **Un-named (N)** | **Lochan Buic** | **McKay 1989** | **McKay 2009** | **Un-named (S)** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *N_TAXA* | 15 | 16 | 11 | 3 | 11 | 11 | 9 | 4 | 13 | 11 | 10 | 8 |
| *LMNI* | 5.50 | 5.26 | 4.71 | 5.82 | 4.72 | 4.16 | 4.38 | 4.80 | 4.71 | 4.77 | 4.66 | 4.79 |
| *Z_col (m)* | 6 | 7 | 6 | 3 | 6 | 7 | 5 | 3 | 5 | n.d. | 5 | 4 |
| *Secchi D (m)* | 3.0 | 3.0 | 2.0 | 0.6 | 1.6 | 2.5 | 0.9 | 1.1 | 1.7 | n.d. | 1.9 | 1.3 |

The LMNI value is the cover-weighted mean of the species' LMNI scores given in Table 4 where R (rare) =1, O (occasional) = 2, F (frequent) = 3, A (abundant) = 4 and D (dominant) = 5.
Z_col refers to the maximum depth of colonisation recorded in each loch, measured to the nearest metre. The Secchi depth indicates the transparency of each water body. Data were not collected for Secchi depth in 2008 and the values presented are all derived from 2009. No data are available from previous surveys.

n.d. = no datum
N_TAXA = number of taxa

### 5.6 Re-surveys of transects in primary lochs first surveyed in 2008

A total of 96 quadrats that were first surveyed in 2008 were re-surveyed in 2009. There were only very minor changes in the composition of species recorded. Consequently, the main focus was on assessing changes in the richness and cover of vegetation in quadrats. Data were analysed by considering individual pairwise differences between the 2009 data and the 2008 baseline for each quadrat (e.g. if a given quadrat contained 10 species in 2008 and 11 species in 2009, the pairwise difference is +1).

Figure 5 illustrates the mean change in number of plant species per quadrat, stratified by loch. The three lochs in which beavers had been active and water levels had been changed due to damming of outflows are also indicated. Generally, as would be expected, there were only very minor changes in the mean number of taxa per quadrat. Increased numbers could be associated with improved detection of smaller herbs occurring at low cover, following an early onset of senescence in naturally more abundant and competitive species, due to poor weather conditions. Detection rates may also have been improved by access to 2008 survey data. The most likely explanation for reduced richness is loss of species due to raised water levels. This may be actual loss or increased difficulty of detecting species at very low cover.

Figure 6 illustrates the mean change in total cover of vegetation between 2009 and 2008 (i.e. a negative value represents a reduction in cover relative to the 2008 value). Again, the overall variation is limited, and predominantly results from variable cover of dominant species (<10%) reflecting survey timing and growing conditions. Additionally, a component of the overall variability will be surveyor error (i.e. the inability to consistently resolve cover more precisely based only on visual assessment). However, Figure 6 does provide some indication that cover is more reduced in those lochs where beavers have been most active. There was no observed evidence that herbivory by beavers has reduced cover at a water body scale. The most likely explanation is, therefore, that any reduction in cover is a consequence of water level rises associated with damming under high rainfall conditions.

Figures 7 and 8 summarise the results by partitioning the lochs into those where beavers have constructed dams, and those which are un-dammed. The latter provide a reference against which the effects of the beavers can be broadly compared. Figure 6 indicates that in those lochs where beavers have not dammed outflows, there was a small average increase of about 0.25 taxa per quadrat relative to the 2008 levels. In the absence of any effects of beavers, this rise would be expected to be seen across all lochs, whereas there was an observed decrease in richness relative to 2008 levels in those lochs with beaver dams. The difference in pairwise change in richness between the two types of lochs (i.e. those with and those without dams) was found to be statistically significant at $p = 0.05$. The differences in the case of cover were more marked. There was a negligible change in cover in those lochs without dams (+2%±4% at 95% CL), but an average 16% reduction in cover in lochs with dams (±6% 95%CL). The difference between the two loch categories was highly significant ($p < 0.001$).

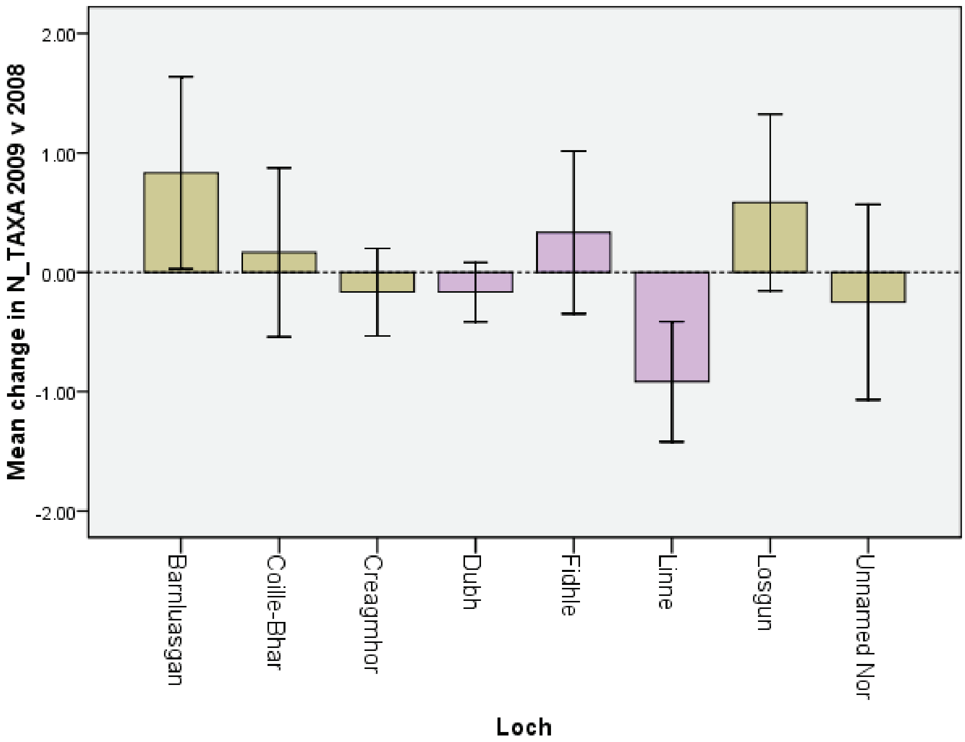


*Figure 5. Comparison of mean change in number of plant taxa in fixed quadrats in eight primary lochs between 2008 and 2009. Lochs shown in lilac have active beaver populations. Bars indicate 95% confidence intervals.*

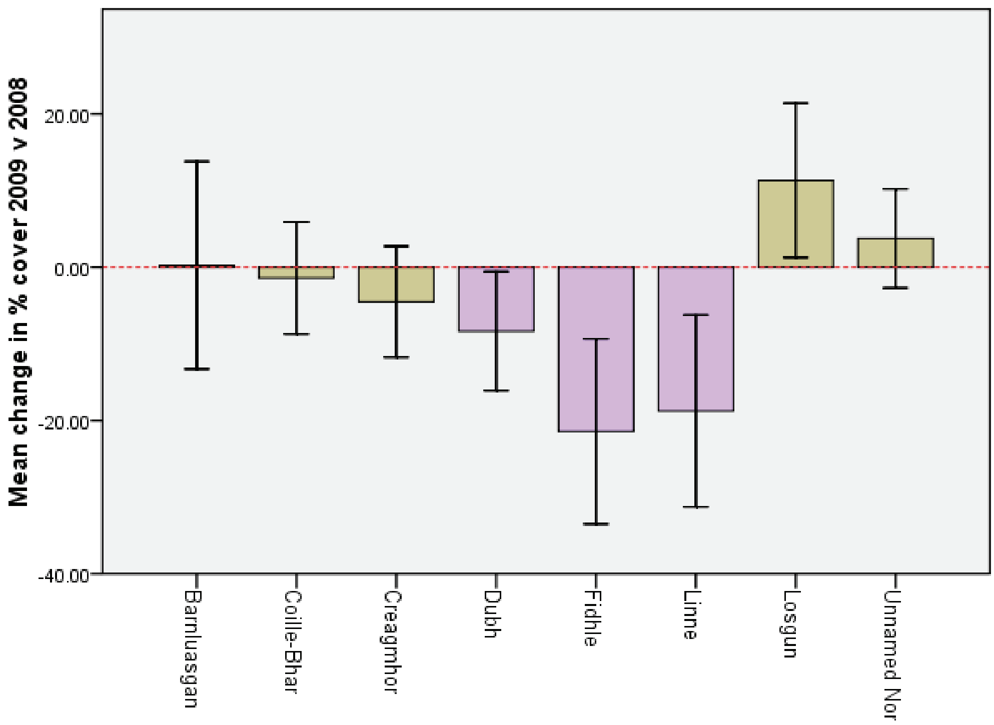


*Figure 6. Comparison of mean change in total percentage cover of plants in fixed quadrats in eight primary lochs between 2008 and 2009. Lochs shown in lilac have active beaver populations. Bars indicate 95% confidence intervals.*

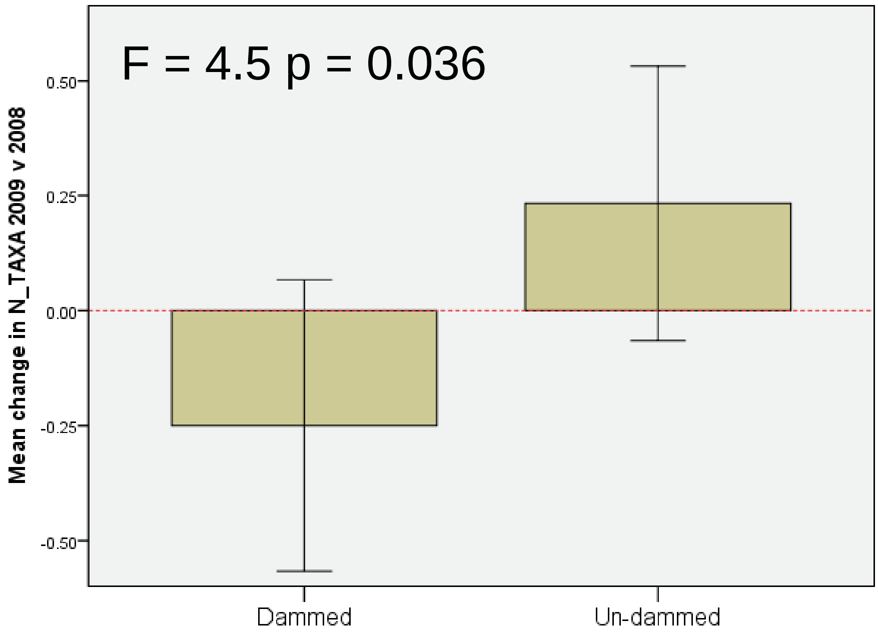


*Figure 7. Summary of change in richness of plants in fixed quadrats in primary lochs, showing weak significant difference in change between lochs with and without beaver dams (One-way ANOVA, F=4.5, p=0.036). Bars indicate 95% confidence intervals.*

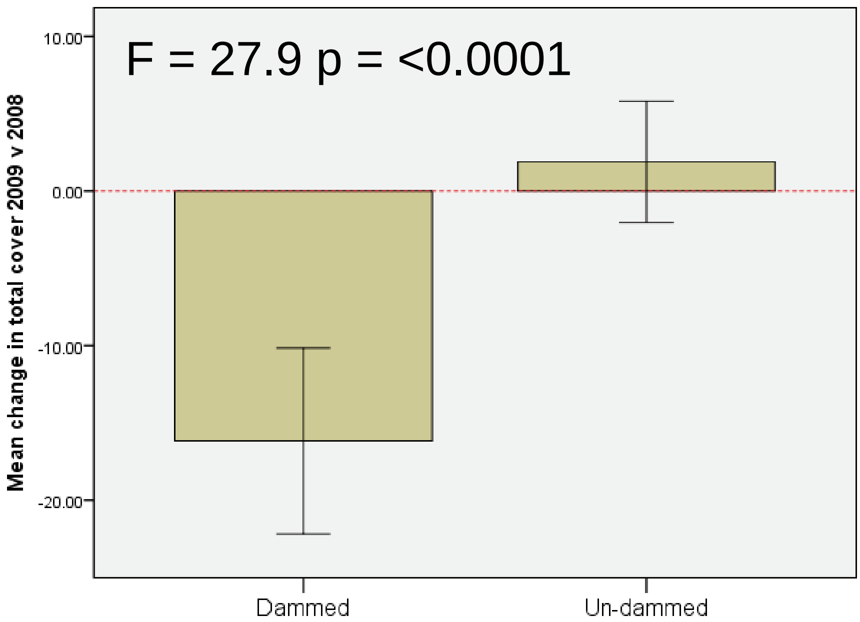


*Figure 8. Summary of change in cover of plants in fixed quadrats in primary lochs, showing strongly significant difference in change between lochs with and without beaver dams (One-way ANOVA, F=27.9, p=<0.0001). Bars indicate 95% confidence intervals.*

## 6 DISCUSSION

### 6.1 Additional primary lochs in the context of the overall resource

The aquatic plant survey data from 2008-2009 are summarised as DAFOR values in whole lake form in Table 4. The species defined as aquatic are submerged or floating-leaved. Only one of the additional primary water bodies surveyed in 2009 had been surveyed comprehensively previously and reference is made to this under the account for Loch McKay given above (5.4). Considering how the primary water bodies surveyed in 2009 fit into the overall vegetation resource at Knapdale, the overall floral composition is similar. The additional lochs add only one species, *Eleogiton fluitans*, to the flora recorded across the eight primary lochs and four secondary lochs in 2008. This is unsurprising given the rather small size and peatiness of the 2009 sites.

The resource of aquatic vegetation at Knapdale (primary and secondary lochs combined) may be evaluated against the total resource in Scotland by assuming that the Knapdale lochs are drawn from a single 10 x 10km square (they in fact occur at the intersect of four squares). In Scotland there are 920 non-minor 10 x 10 km squares (i.e. grid squares not dominated by sea). Across these squares the median number of vascular aquatic plant species is 18 (i.e. submerged and floating-leaved macrophytes, excluding stoneworts, mosses and algae), whereas Knapdale supports 26 such species. Across the resource of non-minor 10 x 10 km squares in Scotland, 26 species equates to the 85$^{th}$ percentile of aquatic plant richness. On this basis, Knapdale presents a resource of relatively high diversity with regard to aquatic plants within the Scottish context.

### 6.2 Status of *Elodea canadensis*

The finding of *Elodea canadensis* in Lochan Buic in 2009 indicates that *E. canadensis* is currently established in three Knapdale lochs, the others being Loch Barnluasgan and Loch Coille-Bharr, where it was first found in 1989 and 2002 respectively. However, there are records of *Elodea canadensis* in the Knapdale-Taynish area dating back to 1965 and an ongoing slow rate of spread would probably be expected. Although the presence of *E. canadensis* at these sites is not desirable, any negative impacts currently appear to have been limited and it is difficult to envisage that, at the water body level, any of the three sites would have supported a significantly different flora prior to their invasion by *Elodea*.

The potential for spread of *Elodea canadensis* to the other water bodies is comparatively limited since they are not hydrologically connected to Loch Barnluasgan, Loch Coille-Bharr or Lochan Buic. Dubh Loch is perhaps the most vulnerable site, being located in close proximity to Loch Coille-Bharr. Regular movement of beavers between Loch Coille-Bharr and Dubh Loch could increase the risk of spread, but the high humic content of Dubh Loch may preclude the growth of *E. canadensis* there. The un-named loch (S) is similarly very close to Loch Buic and has a boardwalk running along its south-west shore. Currently, the most likely agent of spread of *E. canadensis* to other lochs is in association with fishing tackle, especially landing nets, since several of the sites have boats in place and are fished regularly during the summer. However, *E. canadensis* was not recorded in any of the secondary lochs, several of which are also fished regularly. Loch McKay, which has been managed in the past as a fishery, would also have been a likely locus for spread of *E. canadensis* to other Knapdale water bodies, but the species was absent there.

## 6.3 Sources of variation in transect data between 2008 and 2009

The following can be identified as possible sources of variation in vegetation data in all fixed quadrats surveyed in 2008 and 2009.

- A temporal effect due to inter-annual differences in growing conditions that may contribute to improved growth performance of some species relative to others. This may influence the detectability of different species.

- A seasonal effect due to small differences in timing in the survey of quadrats between one year and another that operates independently of any larger inter-annual effect.

- A spatial effect associated with inaccurate relocation of quadrats in different years. In practice this means that there is a small drift in the position of the quadrat such that the area surveyed does not overlap exactly in each year. Due to conspicuous fixed markers, photographs, survey data and GPS readings, spatial error would be expected to be minimised, especially at the landward end of each transect. In open water it is likely that there is reduced overlap in quadrats, although this may be of little consequence due to the setting of all open water quadrats in larger areas of homogeneous vegetation.

- A surveyor effect caused by limitations on the repeatability of visual assessments of plant cover. Thus, at the upper ends of ranges of cover (>50%), differences in the cover of dominant species between years, of ±10%, are probably insignificant.

- A surveyor effect associated with failure to detect or to record a species that was actually present at the time of survey. A slight increase in the average number of species in quadrats in 2009 compared with 2008 is consistent with this source, but it remains impossible to rule out further error of this type.

- Errors associated with data transcription during recording in the field or entry of electronic data. Five records (<1% of the total number) were clearly ascribable to this source and were rectified prior to data analysis. Whilst this minimised the error, the possibility of unknown errors cannot be excluded.

At sites where beavers are active, direct herbivory and water level change may produce changes in the vegetation. Such changes will be detectable provided that they are larger than the effects of the above sources of variability which apply across all lochs.

## 6.4 Observed effects of beavers on aquatic vegetation at Knapdale during 2009

The potential effects of beavers on aquatic vegetation can be considered in terms of direct effects arising from herbivory, or indirect effects associated with habitat modification (principally change in loch water level and reduced shading of margins due to tree felling). These are discussed in turn below. It is important to note that, at the time of these surveys, beavers had only been present on site for four months and it is therefore premature to draw clear conclusions on the possible effects of beavers on aquatic vegetation, whether positive or negative.

The Knapdale lochs contain significant quantities of a range of large rhizomatous emergent and floating-leaved macrophytes for which beavers display strong dietary preferences. There was direct evidence (feeding piles, uprooted material, drifting fragments) of herbivory on *Nymphaea alba*, *Equisetum fluviatile*, *Schoenoplectus lacustris*, *Menyanthes trifoliata*, *Sparganium erectum* and *Cladium mariscus* (Figure 13). In most cases plants were cut or uprooted and the basal tissues and rhizomes consumed, although there was also evidence of direct herbivory on leaves of *Nymphaea alba* at Creagmhor (Figure 14). At Loch Linne, and to a lesser extent Fidhle, there was extensive feeding on *Schoenoplectus lacustris*, as was readily apparent from the piles of drifting cut stems (Figure 15). The length of these stems indicated that beavers had been cutting plants rooted at depths of 1.5-2m. There was little evidence of consumption of the stem itself, rather the basal part of the stem and rhizome were consumed. Random counts of strandline and drifting material, as well as the standing resource suggested that beavers had removed approximately 5-10% of *Schoenoplectus* stems in these lochs. This could be quantified more accurately in future by dedicated sampling. Although there will be natural mortality of stems associated with wind driven wave action, observations in lochs without beavers indicated that this mortality was well below 1%. Losses of *Nymphaea alba* and *Equisetum fluviatile* were particularly marked at Dubh Loch (Figure 20). The above observations are consistent with the available literature on the choice of macrophyte species and plant tissues in beaver diets (Northcott, 1971, 1972; Simonsen, 1973; Jones *et al.,* 2009). There was no evidence of targeting of *Menyanthes trifoliata* (bog bean) which was observed to occur in a captive population in a semi-natural enclosure at Bamff, Perthshire. As predicted in Willby & Casas-Mulet (2010), there was no evidence of herbivory on *Phragmites australis* at any of the lochs.

In the 2008 survey report (Willby & Casas-Mulet, 2010) it was suggested that some species might be affected, not by direct herbivory, but through change in their immediate habitat due to loss of physical shelter provided by other plants. Isoetids, principally *Lobelia dortmanna* and *Littorella uniflora* growing beneath *Schoenoplectus lacustris* are a particular case in point. At Loch Linne in particular there was a significant volume of drifting or stranded isoetid plant material that had not been seen in 2008. We could find no evidence that beavers were directly consuming submerged isoetids and it therefore seems most likely that this material was generated during uprooting of *Schoenoplectus* rhizomes by beavers. It should be emphasised that some loss of isoetid plants is to be expected in any loch as a natural consequence of wave–induced disturbance of the sediment and therefore it is very unlikely that beaver activity alone is responsible for the uprooted isoetid plants observed. Quantification of volumes of strand line material, relative to the loch resource, is planned for selected species in 2011, in lochs with and without beavers, to improve estimates of different sources of macrophyte loss in the Knapdale lochs.

At Loch Linne, beavers had erected a double dam on the outflow at the time of the survey in 2009. The first structure, closest to the loch, was quite low, spanned a relatively wide section of channel (15-20m) and accounted for an estimated rise in water level of only about 0.1m (Figure 17). Approximately 100m downstream was the larger dam (Figure 18), which was constructed at the narrowest part of the channel and was readily visible from the adjacent forestry track. This dam was well maintained by beavers, and accounted for an estimated rise in water level of about 0.2m, despite initial attempts to remove it by the Scottish Beaver Trial. It is a condition of the release licence that dams on the outflows of lochs within the SAC will be managed (by alteration or removal), to ensure that water levels are unaffected. However, the dams on the outflow of Loch Linne had produced a 0.2-0.3 m rise in water level, on Lochs Linne and Fidhle, which was readily evident at the terrestrial end of the fixed transects established in 2008 (Figure 16). The effect of the dams in storing water was also undoubtedly accentuated by the poor weather and persistent rainfall during August 2009. Shortly after the survey, the dams were removed by the Scottish Beaver Trial and the beavers have not re-built them at the time of writing.

Two key points should be made in relation to the effects of dam-induced increases in water levels on aquatic vegetation. First, the lochs currently have rather stable water levels, since each water body area is large relative to its catchment area. Hence the observed water level rise accounts for a large fraction of the mean annual water level range. Based on stage board data collected every 2 months, water levels fluctuated by between 0.15m and 0.35m in

2005. As the lochs are of low nutrient status, existing vegetation is likely to be more sensitive to water level change. Second, all the lochs are coloured, limiting transparency (typically to around 1.5-2m, but in some cases more severely). Consequently, a water level rise may represent a relatively large proportion of the euphotic depth and this is likely to magnify the effect on aquatic vegetation. Rate of vegetative response to changed water levels is likely to be constrained by the low fertility of the lochs. The first response will be a reduction in open water vegetation from absolute current position due to physiological constraints. Nominally, the position of nymphaeid beds is expected to migrate landward relative to the current shoreline, thereby maintaining the same maximum rooting depth (typically 3m). In some sites, such as Dubh Loch, which have extensive willow and alder carr growing in shallow water, the scope for landward migration of open water macrophytes is likely to be severely limited due to heavy shading of the littoral zone by woody vegetation. In such cases, there is likely to be a marked reduction in the extent of both emergent and floating-leaved vegetation, unless the carr itself recedes.

In water bodies such as Loch Linne and Loch Fidhle, if water levels remain elevated, ultimately, the status of open water vegetation would be expected to stay the same *in the long term*, through expansion into currently shallow water areas occupied by emergent vegetation. However, it may be several years (5-10) before cover stabilises at 2008 levels. Some changes in the relative abundance of different species might also be anticipated. For example, smaller emergent species that are tolerant of variable water levels, such as *Carex rostrata*, might be expected to increase. In some locations, loss of emergent plants from exposed areas of shore due to increased wave action might occur. Some evidence of increased disturbance to beds of *Cladium mariscus* along the north-east shore of Loch Linne was observed in 2009. *Potamogeton natans*, which is able to adjust more rapidly to changing levels and to spread vegetatively into vacated patches, might also be expected to benefit at the expense of *Nymphaea alba*.

The dams on the outflow of Loch Linne were manually removed in late November. If water levels quickly return to their pre-introduction regime, it is highly likely that the quadrat level changes seen in 2009 will be reversed. Re-survey of the same fixed quadrats in 2011 will determine if this is the case.

Tree felling was not monitored specifically, since woodland monitoring is being undertaken as part of a different project by the Macaulay Land Use Research Institute, in partnership with SNH. Several observations can, however, be reported (Henry Dobson, pers. comm.), viz:

- There is a strong emphasis on felling of young willow in the normal preferred size range (i.e. diameter at breast height of 2-8cm; Kindschy, 1985). Birch is the only other species taken in quantity.

- There is a considerable amount of felling up to 40m from the water's edge at Lochs Linne and Fidhle. This is much further than observed at a captive colony at Bamff, Perthshire. The rate of decline in felling with distance is also much less pronounced at Knapdale. Much of this felling is not visible from the water.

- In an outflow stream at the southern end of Loch Fidhle, beavers had felled 10% of the resource of 990 available trees. Nearly all trees felled were willow. At several sites around Loch Linne, beavers felled 5% of an estimated resource of 5500 trees, within the blocks surveyed. Willow accounted for more than half the trees felled, even though they accounted for only 15% of the available resource.

- There was relatively heavy and selective felling of rowan at Lochs Linne and Fidhle (10% of trees felled, but only 1% of the available resource). This may reflect the very heavy berry crop on rowan in 2009.

On the basis of these observations, large scale modification of the riparian zone through tree felling seems unlikely, except perhaps in the immediate vicinity of lake outflows, such as at Loch Linne.

## 6.5 Implications for future monitoring

Based on the experience of surveys in 2009, several points should be considered in relation to future monitoring.

1. Surveys in late September may be compromised by early die back of plants if growing conditions during August are affected by poor weather, as they were in 2009. High rainfall may accentuate this effect. End of season surveys should therefore be carried out in the first two weeks of September to enable the appraisal of increases in water levels, linked to beaver dams.
2. The survey of a fixed subsample of quadrats (minimum of three transects) in each primary loch in intervening years (2011 and 2013) is a sensible future strategy and will ensure detection of larger-scale effects.
3. Willby & Casas-Mulet (2010) had originally suggested that surveys of fixed transects should be repeated annually. Restricted resources mean that sampling frequency will be limited to biennial surveys. This should reduce the effect of trampling on quadrats that might occur with annual surveys and is therefore preferable.
4. At some locations (e.g. north end of Loch Barnluasgan), there was evidence of trampling associated with downloading of water-level data loggers. This needs to be reduced over the remaining years of the survey.
5. Re-surveys of the same subsample of fixed transects in May and September 2011, and of all transects in May and September 2013, will allow for detection of within and between-year effects at different sites.
6. Transects chosen for subsampling in primary lochs can mostly be accessed on foot. This saves time in loading and unloading a boat. Where accessed on foot, surveys must be carried out by snorkelling or underwater observation by bathyscope, as would be done from a boat, and not by destructive sampling using a rake.
7. Due to the limitations of GPS resolution, it would be beneficial to supplement sampling of fixed transects with manual measurements from the transect marker to the outer limit of floating-leaved vegetation following a fixed bearing.
8. Bathymetric mapping of primary lochs would provide useful information. Based on morphometry, water transparency and maximum rooting depths, it would be possible to predict the effects of water-level change in individual lochs on the distribution of dominant species. These predictions might then serve as a template for assessing actual distributions at the conclusion of the trial.
9. Willby & Casas-Mulet (2010) noted that with the current survey design it would remain difficult to quantify accurately some specific effects of beavers on aquatic vegetation. The reasoning for this was that herbivory by beavers is often concentrated in very small but highly dispersed patches that have a low probability of coinciding with fixed quadrats (Jones *et al.,* 2009). From observations in 2009, it remains our view that an alternative approach is needed to quantify impacts of herbivory accurately. At the time of this investigation, it was only possible to establish the location of feeding areas rather than to undertake quantitative assessments. The latter would require siting new quadrats in favoured feeding areas, sorting and quantifying plant remnants from feeding piles, or sampling individual plant beds, to quantify changes in stem density over the course of the growing season. *Schoenoplectus lacustris* in Loch Linne and Loch Fidhle may be a particularly good subject for detailed investigation,

as plants are large, easy to quantify and form persistent remains once cut by beavers. An exclosure study might be required to create control treatments at the same site. Quantitative survey of strandline vegetation in a range of lochs may also be a useful approach to assess the additional mortality of plants, in lochs with beavers, relative to the available plant resource.

10. Where damming activity by beavers creates additional areas of standing water (i.e. outside of the original lake basin), consideration should be given to monitoring the vegetation that develops within these aquatic habitats. This monitoring should be restricted to the final year of the trial and is currently only relevant to Dubh Loch.

# 7 CONCLUSIONS & RECOMMENDATIONS

This report and supporting GIS provide a detailed baseline statement of the macrophytic vegetation of three additional primary lochs at Knapdale in 2009, and consider the results of re-surveying a subsample of fixed quadrats, established on the eight other lochs in the release area, in 2008. The principal conclusions of the work are documented below.

- At the current time most of the primary lochs support an aquatic vegetation that is characteristic of oligotrophic or mesotrophic waters. *Nymphaea alba* and *Potamogeton natans* are the most abundant and widely distributed species, which is consistent with the high humic content of the water in many of the smaller lochs, most notably Dubh Loch. In the larger, clearer lochs, such as Loch Barnluasgan and Loch Coille-Bharr, the high diversity of pondweed species is notable.
- The discovery of *Elodea canadensis* in Lochan Buic suggests that there is a slow underlying spread of this species in the area, which has been underway since the 1960s and which has already included Lochs Barnluasgan and Coille-Bharr. Although well-established in these lochs, impacts of *Elodea* on native vegetation at the whole-lake scale appear to be largely neutral.
- Re-survey of fixed quadrats in primary lochs surveyed in 2008 reveals a number of sources of spatial, temporal and surveyor-related variability. However, these appear to be small, alongside the effects on vegetation caused by water-level rises associated with the presence of beaver dams on loch outflows.
- At present, the most significant effect of beavers on aquatic vegetation is related to the rise in water levels caused by damming of outflows. This is a particular feature of Loch Linne, Loch Fidhle and Dubh Loch, although observed effects are potentially reversible with timely dam removal. A range of species may be affected at a local level by direct herbivory. Probably the most significant effects are on *Schoenoplectus lacustris*, which harbours a dense understorey of isoetids that also appear to be vulnerable to increased disturbance linked to uprooting of *S. lacustris*.

Following consideration of experience to date, a number of recommendations on survey design have been developed.

- Baseline and future surveys should be seen as part of a tiered approach to the monitoring of aquatic vegetation. A single full survey of all primary lochs, including full polygon mapping to the same level of spatial resolution as used in baseline surveys, should be undertaken at the close of the trial.
- Resurveys of a proportion of fixed quadrats should be undertaken in spring and late summer in all primary lochs, but no later than the second week in September. Biennial surveys have the benefit of reducing the effects of trampling on vegetation. The existing number and arrangement of quadrats appears to be adequate to detect lake level effects, such as change in water level.
- Annual checks may be necessary in some lochs to assess potential responses to changes in water level or water-level regime.
- Additional quadrats, or grazing exclosures may need to be established in some lochs to adequately quantify effects of herbivory, which can be highly concentrated in very small but highly dispersed patches.
- Unless there is evidence from tracking or feeding that beavers have been utilising secondary lochs, there will be limited value in re-surveying these during the trial.

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## 9 PLATES - Representative photographs for each loch

*Figure 9. Lochan Buic looking east from SW side over* Cladium *bed*

*Figure 10. Lochan Buic. Mixed bed of* Eleogiton fluitans *and* Sparganium angustifolium*.*

*Figure 11. Loch McKay. Looking NE from SW corner over* Carex rostrata *bed and low density* Nymphaea alba

*Figure 12. Un-named loch (S). Looking S from N corner over* Schoenoplectus lacustris *and* Nymphaea alba *bed.*

*Figure 13.* Cladium mariscus *stems cut by beavers at southern end of Loch Fidhle*

*Figure 14. Remnants of macrophytes, principally* Nymphaea alba*, associated with beaver feeding, southern end of Loch Creagmhor*

*Figure 15. Rafts of* Schoenoplectus lacustris *cut by beavers at south end of Loch Linne. The outflow is in the middle background.*

*Figure 16. Terrestrial quadrat on fixed transect at southern end of Loch Fidhle showing* Myrica *mire inundated by rise in water levels associated with damming activity.*

*Figure 17. Secondary beaver dam on outflow from Loch Linne. The water-level rise associated with this dam was ~0.1m.*

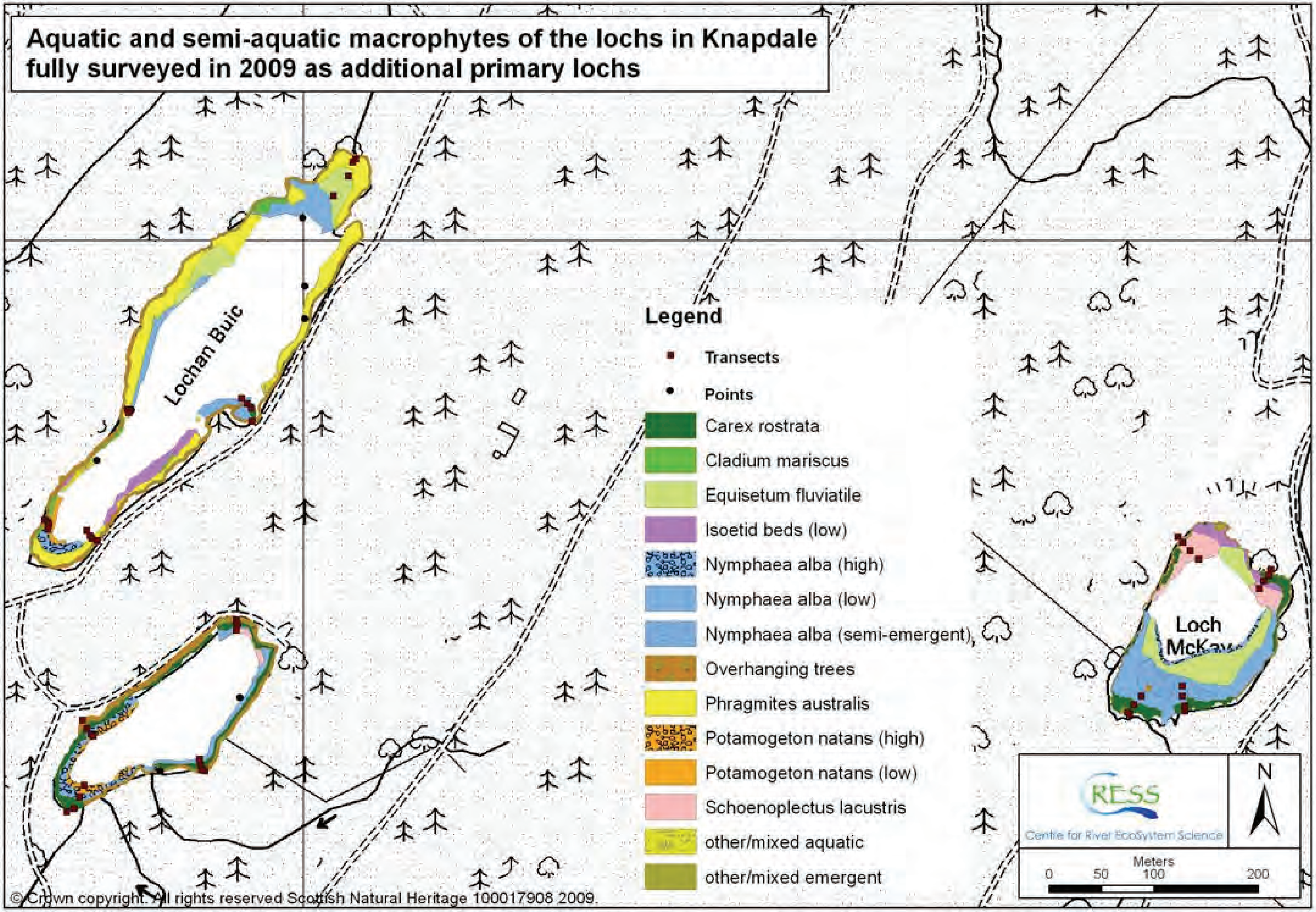
*Figure 18. Main beaver dam on outflow from Loch Linne. This dam accounts for ~0.2m rise in upstream water level and is situated in the narrowest part of the channel.*

*Figure 19. Dubh Loch in 2008 looking north eastwards from south westerly apex over extensive mixed beds of floating-leaved vegetation. Note continuous fringe of* Equisetum fluviatile *to right of picture and steep wooded scarp.*

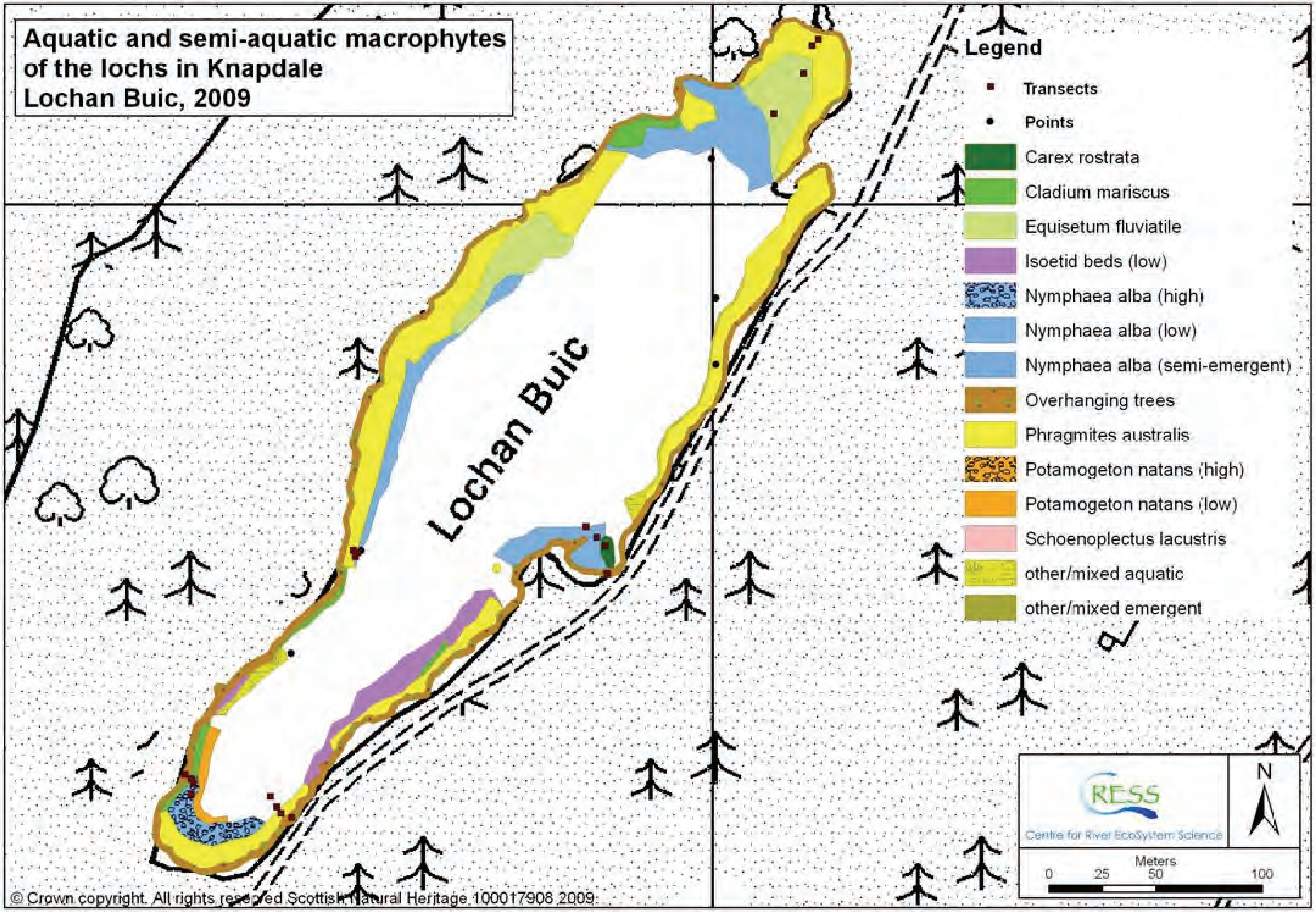
*Figure 20. View from fixed transect at southern end of Dubh Loch in 2009. Note rise in water level, loss of* Equisetum fluviatile *fringe visible in Figure 13 and disturbance to* Equisetum, Carex paniculata, Menyanthes trifoliata *and* Nymphaea alba *in foreground, possibly associated with temporary lodge construction.*

## APPENDIX 1. Vegetation maps for primary lochs

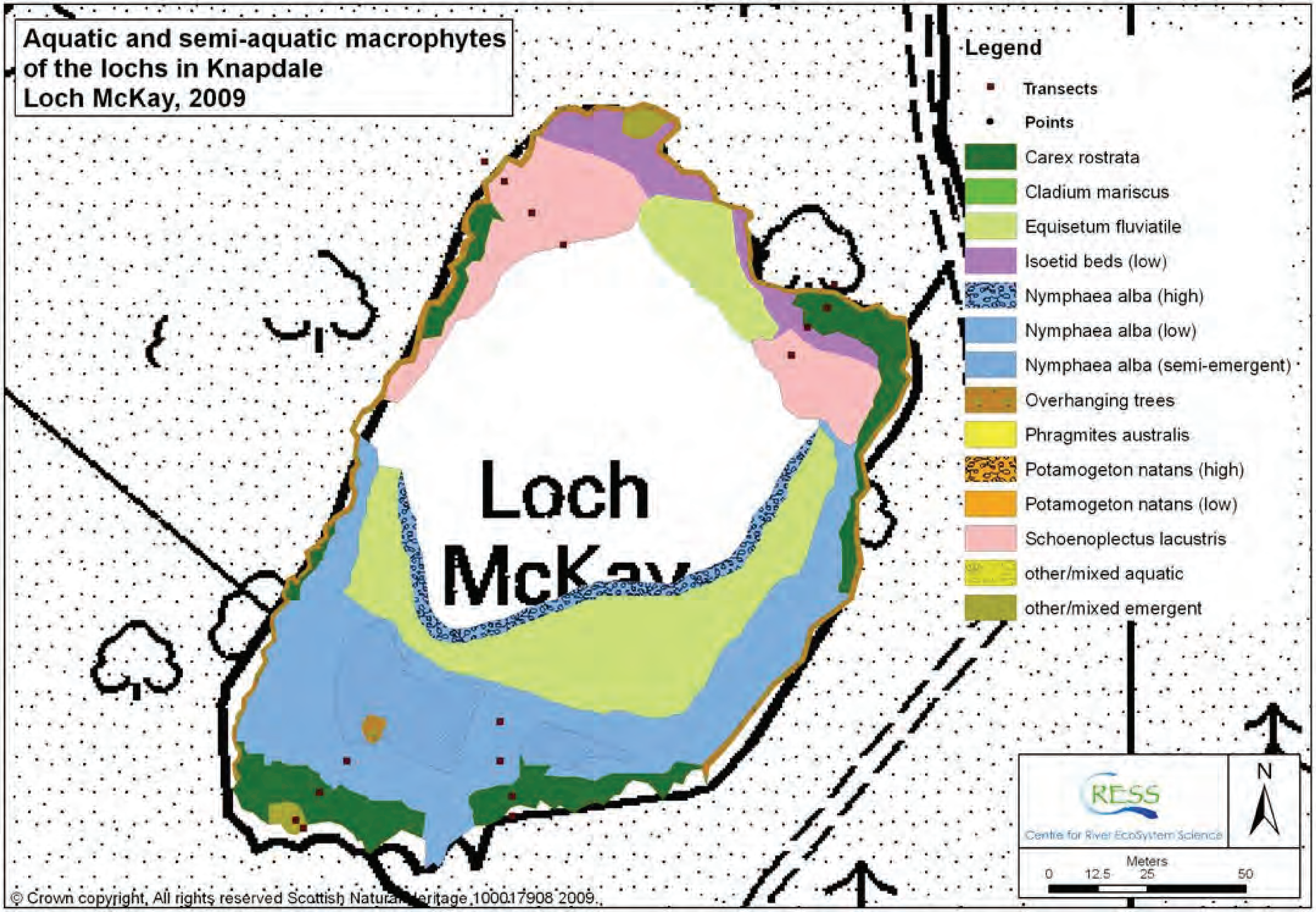
*Map 1. Overview of polygon distribution in additional primary lochs*



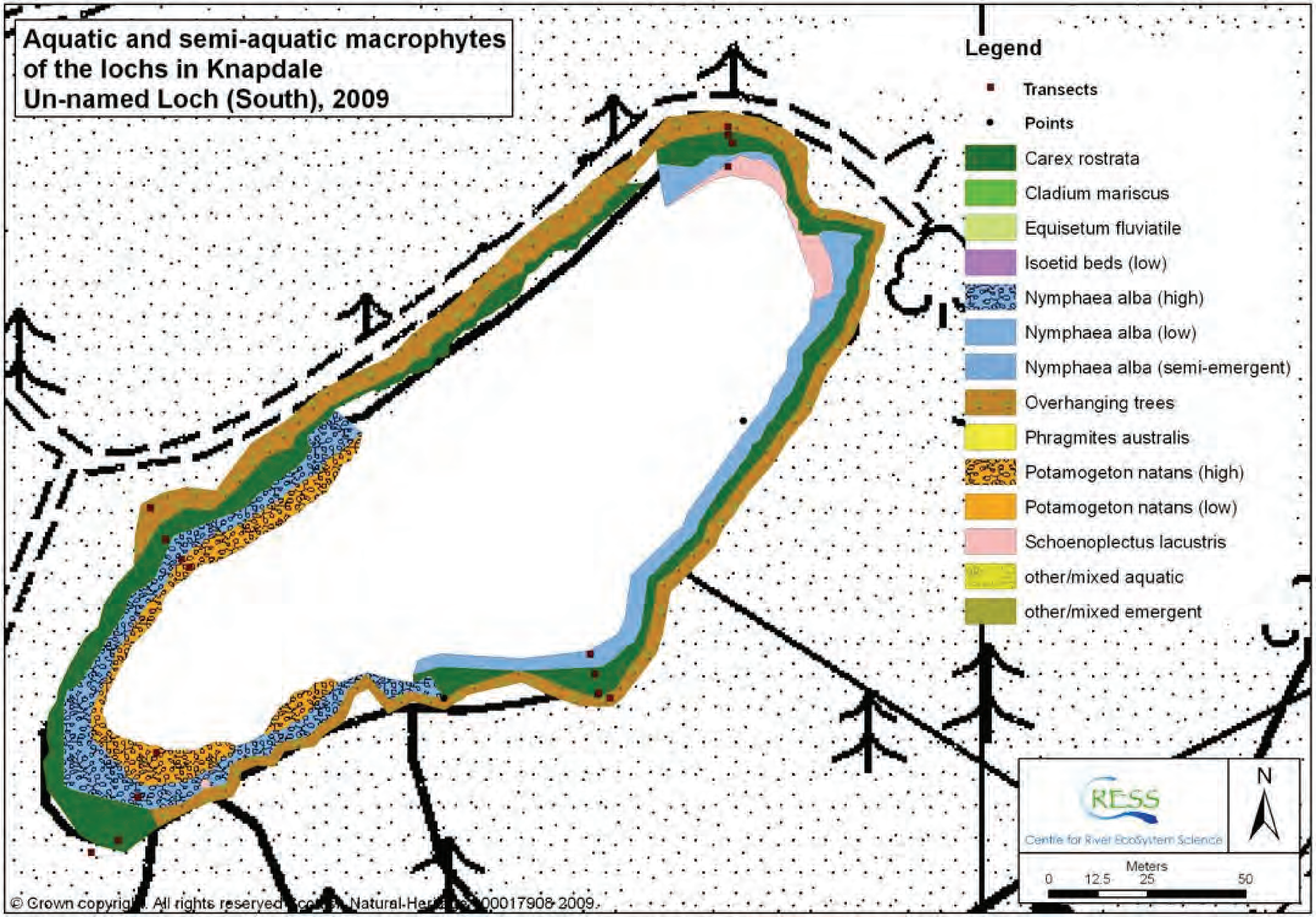
*Map 2. Polygon, point and transect distribution in Lochan Buic*



*Map 3 Polygon, point and transect distribution in Loch McKay*



*Map 4. Polygon, point and transect distribution in un-named loch (S)*



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Policy and Advice Directorate, Great Glen House,
Leachkin Road, Inverness IV3 8NW
T: 01463 725000

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