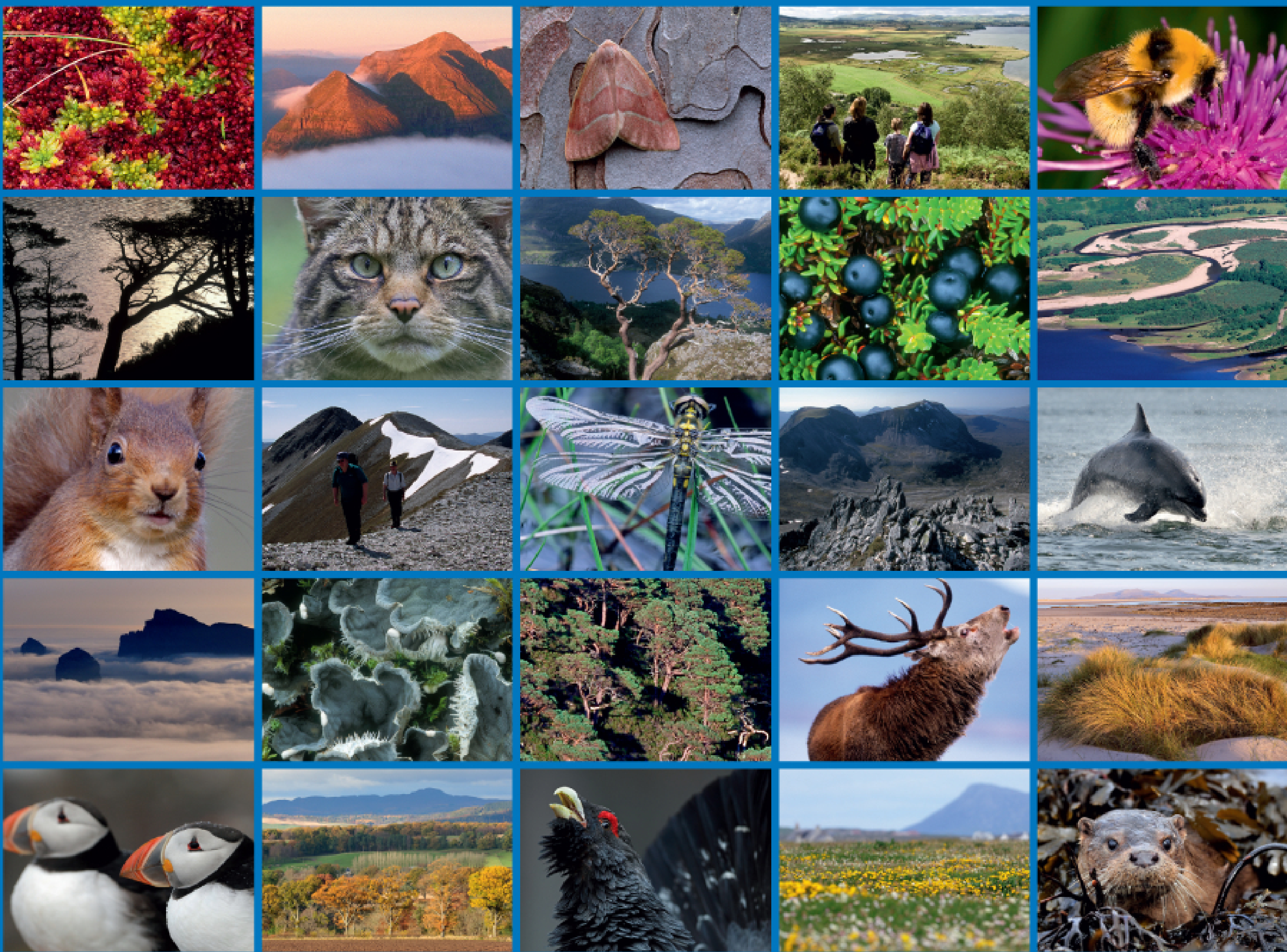
Scottish Natural Heritage
Commissioned Report No. 391

The Scottish Beaver Trial: Baseline survey of the aquatic and semi-aquatic macrophytes of the lochs 2008



COMMISSIONED REPORT

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The Scottish Beaver Trial: Baseline survey of the aquatic and semi-aquatic macrophytes of the lochs 2008

(*iBids No. 7062*)

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: Baseline survey of the aquatic and semi-aquatic macrophytes of the lochs 2008

Commissioned Report No. 391 (iBids No. 7062)
Contractor: Centre for River EcoSystem Science, University of Stirling
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Background

A five-year trial reintroduction of the European beaver at Knapdale, Argyll, commenced in spring 2009. An independent monitoring programme has been established that will consider, *inter alia*, the impacts of beavers on the aquatic vegetation of lochs within the Knapdale area. These lochs form a key feature of interest of the Taynish and Knapdale Woods Special Area of Conservation. 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 beavers' release. This monitoring will also yield data of suitable quality and resolution to discriminate between a range of possible future influences on lake vegetation.

This report provides a review of the previous methods used in surveys of aquatic macrophytes at Knapdale and considers their appropriateness for future monitoring. It then provides a comparison between the results of previous surveys and those conducted to a standard methodology in 2008, leading to recommendations for future surveys.

Main findings

- The 2008 survey established that the primary lochs support a high quality aquatic vegetation that is characteristic of oligotrophic or mesotrophic waters. Notable features are the diversity of pondweed species and the presence of sizeable populations of several nationally or locally scarce species.
- Most of the secondary lochs are affected by significant water level fluctuations and, with the exception of Lochan Duin, are sparsely vegetated.
- Detection bias and identification inconsistencies impose severe restrictions on species level comparisons between lake macrophyte surveys that have used different methods or observers. Invasion of two lochs by *Elodea canadensis* marks the only significant change in the vegetation of the Knapdale lochs to have occurred during the last two decades.
- Significant impacts of beavers on aquatic vegetation in the Knapdale lochs are unlikely, although herbivory would represent an additional disturbance, which, in naturally less productive lakes, could lead to contraction of the cover of preferred species in certain areas.
- Future monitoring should include a repeat of the current survey design at the conclusion of the trial, plus annual surveys of fixed quadrats supplemented by targeted surveys of beaver feeding areas, in interim years.

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

For further information on beaver issues in Scotland or 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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1. INTRODUCTION

In May 2008 the Scottish Government approved a licence for a five-year trial reintroduction of the European beaver to Knapdale, Argyll, where beavers were released in spring 2009.

The primary aims of this trial include a study of the ecology and biology of the European beaver in the Scottish environment and an assessment of the effect of beaver activities on the natural environment. The success of the trial will be judged against criteria that include positive contribution to ecosystem function and an absence of significant or unsustainable damage to ecosystems within the release site.

The trial is contingent on an independent monitoring program me that will consider, *inter alia*, the impacts of beavers on aquatic vegetation of lochs within the Knapdale area. To support this monitoring, it is therefore critical that an adequate baseline data-set is collected that establishes, in a cost effective manner, the condition of the vegetation in these lochs in advance of the beaver release. This monitoring should also yield data of suitable quality and resolution to discriminate between a range of possible future influences on lake vegetation. Interpretation of observed changes in vegetation will be aided by environmental data provided by automated recording of water level fluctuations and regular measurements of various water chemistry determinants (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 mechanisms, both direct and indirect, at local or larger scales, and over the short or longer term. These mechanisms range from grazing of preferred species leading to rapid but localised reductions in cover (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 activity (Pollock *et al*., 2003). Although it is evident that beavers can have an impact upon the composition and biomass of herbaceous vegetation by direct herbivory, such effects are rather poorly researched; impacts of beavers on herbaceous vegetation are typically attributed to the indirect effects of habitat modification (Parker *et al*., 2007).

In the present context aquatic vegetation is of added significance, since the release sites are located within Taynish and Knapdale Woods Special Area of Conservation (SAC). The presence of extensive tracts of sessile oak woods with *Ilex* and *Blechnum* is the primary reason for the designation of this site. However, aquatic vegetation is also a qualifying feature, specifically the standing water feature of oligotrophic to mesotrophic standing waters with vegetation of the *Littorelletea uniflorae* and/or of the *Isoeto-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. Assessing the response of aquatic vegetation at this site to the reintroduction of beavers is consequently an important element of the trial. It is a condition of the licence that dams on standing waters within the SAC must be managed to ensure that water levels remain unchanged. Direct herbivory may, accordingly, be a more significant component of the effects of beavers on aquatic vegetation at Knapdale.

Eight primary lochs and four secondary lochs were identified for survey, either because they are likely to be the beaver release sites, or because they lie within the general release area. The primary lochs are release sites or lie adjacent to release sites and might therefore be colonised by beavers. With the exception of Loch Losgunn, all the primary lochs lie within the Taynish and Knapdale Woods Special Area of Conservation (SAC). The secondary lochs are a series of reservoirs situated on the edge of the release area and could potentially be utilised by beavers, if animals range more widely. The primary and secondary lochs and their characteristics are listed in Table 1, and their locations are shown in Figure 1.

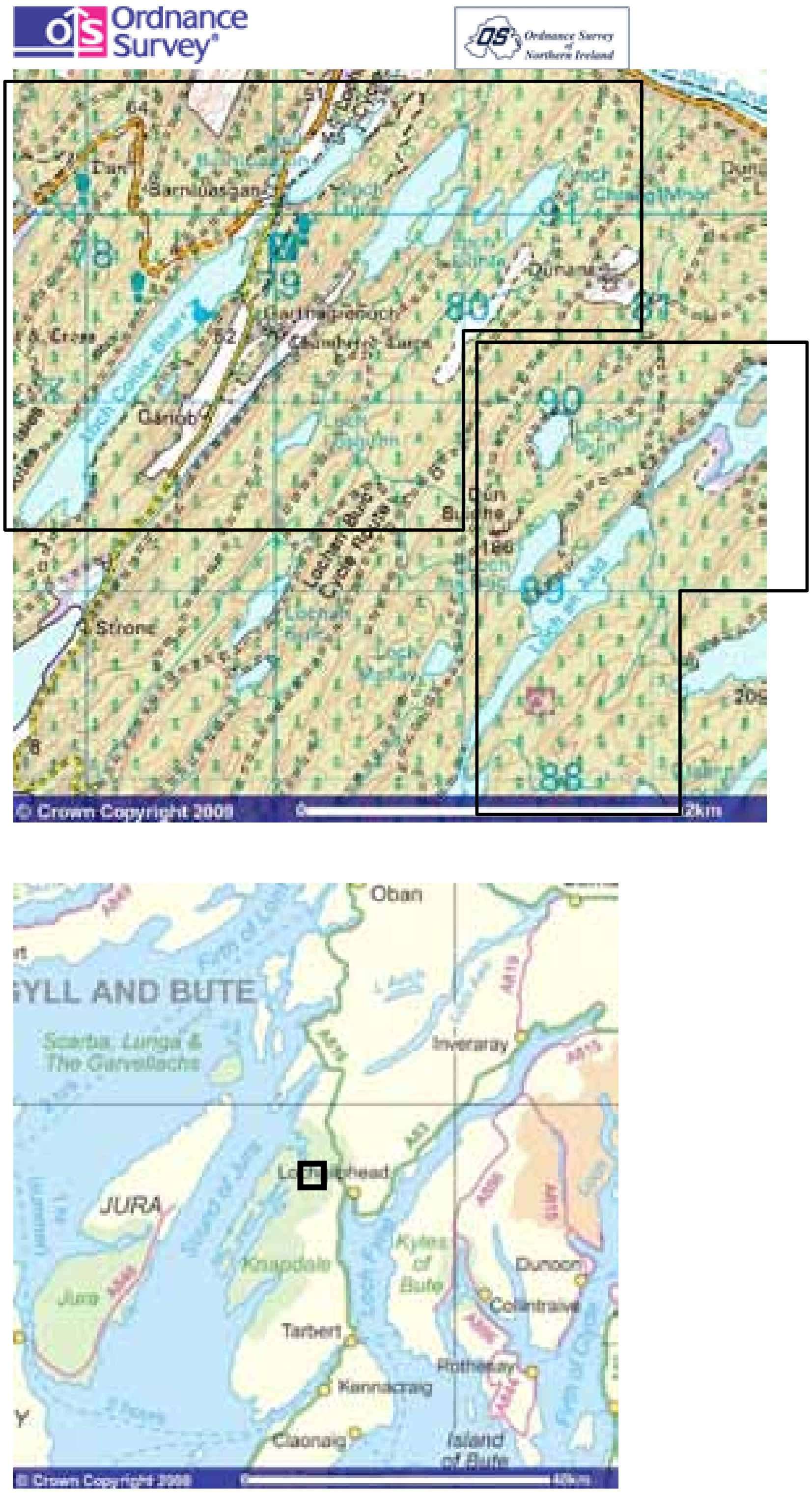

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Figure 1.
Upper: location of primary (upper left panel) and secondary (lower right panel) lochs at Knapdale. Lower: general geographical context. Inset shows area of enlargement.

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

Loch name	**Grid reference**	**WBID**[1]	**Alkalinity (meq/L)**[2]	**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	0.54	43	5.3	1.2	10-15
Loch Coille-Bharr	NR782901	25179	0.47	32	33.4	4.4	10-15
Loch Fidhle[6]	NR799909		0.21				5-10
Loch Linne	NR797910	25145	0.22	39	16.5	3.1	10-15
Loch Losgunn	NR791898	25209	0.08	68	2.1	0.7	5-10
Un-named loch (N)[7]	NR801910	25168	0.10	68	1.1	0.5	<5
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 data are based on single samples collected in June 2002 and analysed by SEPA.
3 There is no measured bathymetry for any of these lochs. The maximum depths are based on modelled maxima, as given in the GB Lakes Inventory, or estimated during field surveys. The true maximum depths probably exceed 15m in Coille-Bharr and Linne.
4 Alkalinity was estimated from the nearest adjacent lochs.
5 Various derivations of this name are 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 In the GB Lakes Inventory this is erroneously labelled as Loch Fidhle.

2. BACKGROUND

Presently, there are three sets of data on macrophytes of the Knapdale lochs.

(i) NCC/SNH Scottish Loch Survey Project (SLSP)
The lochs surveyed, in July and August 1989, were Loch Coille-Bharr, Loch Barnluasgan and Loch Linne. The surveyors walked around these lochs, to wader depth, recording the macrophytes present. A grapnel was used to sample in deeper water, from the shore and from a boat. A sketch map of the vegetation, a macrophyte species list and a record of abundance of each species, using the DAFOR scale (dominant, abundant, frequent, occasional, rare), were produced. The method used is described by Lassiere (1998).

(ii) Baseline surveys for beaver release sites (Murphy *et al*., 2002)
Baseline surveys were carried out in June 2002. The primary lochs surveyed were Loch Coille-Bharr, Loch Barnluasgan, Loch Linne, Loch Fidhe, un-named Loch (North), Creagmhor Loch (also referred to as Loch Creige Moire), and Loch Losgunn. The secondary lochs surveyed were Lochan Duin, Loch na Bric, Loch an Add and Loch Daill. For the primary sites, work involved a general survey of the macrophytes (following the SLSP methodology), and fixed transects and quadrats, the latter approach to allow assessment if finer scale changes occurred in the macrophyte community in future, following the anticipated release of beavers at Knapdale in 2003. For the secondary lochs, a species list was produced, with DAFOR ratings, the approach used following the SLSP methodology.

(iii) Site Condition Monitoring
In June 2004, partial surveys were undertaken of Loch Coille-Bharr, Loch Barnluasgan and Loch Linne. Two to three sectors were examined at each loch. A perimeter search and five short transects, each with four sampling points, were undertaken at each sector, following the method described by Gunn *et al.* (2004). Presence/absence data were collected for each sampling point. No work was undertaken by boat.

Although the above surveys have been undertaken, there are limitations to the data available, so a further baseline survey was required. The reasons for this are documented below.

(i) A problem which is faced repeatedly in studies of lochs is that there are insufficient data to quantify naturally occurring variation in the macrophyte communities, so it is difficult to reach reliable conclusions as to whether there have been changes caused by a particular pressure that are over and above the changes that would be expected due to natural variation. A resurvey of macrophytes in 2008 adds to the body of information on natural variation.

(ii) Although baseline data were collected by Murphy *et al.* (2002), these data will be seven years old by the time of the release of beavers in May 2009. If any pressure has been causing impacts on the lochs in the interim, there is a danger of future uncertainty over the cause of any change in the vegetation, if this pressure is not identified now.

(iii) The standing water feature has been judged to be in unfavourable condition, due to the pressure of *Elodea canadensis*. This species has been recorded in Loch Coille-Bharr and Loch Barnluasgan. Colonisation of lochs by *E. canadensis* potentially leads to changes in macrophyte community composition and structure. A survey in summer 2008 will establish the degree of alteration in the macrophyte community and structure, before the beavers are released. Note that in considering the effects of pressures on SAC interests, there is a requirement to examine them both alone and in combination with other pressures.

(iv) Although there are three sets of macrophyte data different survey methods have been used for data collection, and for different purposes.

a) The purposes of the SLSP surveys were to document a macrophyte species list and some information on abundance of each species, to characterise each loch and to create a map of the distribution of the dominant macrophytes. Only gross changes in the macrophyte community would be evident in comparing these data with data collected later.

b) The SCM method was developed to identify only those sites which are not in favourable condition. It was designed to collect more robust data than the SLSP method, by recording presence/absence data, over many sampling points, rather than using the DAFOR scale. However, in Knapdale Woods SSSI, collection of data for SCM was limited and did not involve use of a boat. At the time when the first SCM surveys were carried out, a limited number ofspecific sectors in the lochs were surveyed, with the main purpose of assessing whether characteristic species were present at greater frequency of occurrence than uncharacteristic species. This approach was necessary due to the large number of lochs incorporated in standing water features of designated sites and the limitation of resources.

New targets have been developed for assessment of the condition of standing water features (JNCC, 2005) and more survey effort will be required in future. However, in cases requiring more detailed information, or further investigation, e.g. into the effects of a particular pressure, separate surveys are recommended (JNCC, 2005). It is accepted that targeted, detailed survey is more appropriate in these cases, than use of the SCM method.

c) The purpose of the survey of Murphy *et al.* (2002) was to provide baseline data, to allow comparisons to be made before and after the release of the beavers.

(v) No single survey method was applied to all of the lochs (see Table 2).

Table 2. Summary of past macrophyte surveys and survey approaches in Knapdale lochs

Loch name	**SLSP (1989)**	**SCM (2004)**	**Baseline (2002)**
Primary Lochs			
Dubh Loch			
Creagmhor Loch			X
Loch Barnluasgan	X	X	X
Loch Coille-Bharr	X	X	X
Loch Fidhle[6]			X
Loch Linne	X	X	X
Loch Losgunn			X
Un-named loch (N)			X
Secondary Lochs			
Daill Loch			X
Loch an Add			X
Loch na Bric	X		X
Lochan Duin	X		X

3. OBJECTIVES

The main objectives of this contract are presented below.

1. Review the methods which have been used in previous surveys of these lochs, with respect to their suitability for monitoring the effects of beavers on aquatic and semi-aquatic vegetation.

2. Considering cost-effectiveness, design a strategy for a baseline survey of the submerged, floating-leaved, edge and emergent flora in each loch, and for subsequent monitoring of these lochs, over the period of the trial. The baseline survey method should be adequate to detect localised impacts as opposed to whole lake effects, and must ensure that variability associated with application of this method is sufficiently small to ensure that effects attributed to beavers are real.

3. Undertake a baseline survey of each loch, which will allow comparisons to be made between results collected before the beavers are released and those from monitoring following beaver release.

4. REVIEW OF PREVIOUS SURVEY METHODS

Among the criteria that have been proposed to indicate the failure of the reintroduction trial are the presence of significant or unsustainable damage to natural ecosystem features, while success would be judged partly on the presence of positive contribution to ecosystem function. With this in mind and, given that beavers are likely to impact directly or indirectly on aquatic vegetation (whether positively or negatively), it is argued that the key considerations in survey design are:

1. the ability to detect change and
2. the ability to discriminate between changes due to external factors and those attributable to beavers.

Based on these considerations the following observations are offered on previous survey methods.

4.1 Scottish Loch Survey Project (SLSP) method

The SLSP method (Lassiere, 1998) is a flexible survey approach that could be conducted at all lochs. The existence of data from 1989 and 2002 for some sites is useful for long-term comparisons. However, maps generated using this approach need to be interpreted cautiously, as loch surveys were undertaken by different observers.

Potentially, the SLSP design would be useful for detecting whole-lake or within-lake impacts of moderate to high intensity. Excluding major biological invasions whole-lake impacts are very unlikely during this project due to the characteristics of the lake catchments, and because potential effects of water level changes caused by dams will generally be mitigated through removal of beaver dams. More local impacts may occur (e.g. reduction in the area of stands of dominant species due to to herbivory), but these would need to be fairly large-scale and larger than the variability that exists between surveys, as a function of time and observer, in order to be detected by this approach. Consequently, this method is regarded as too coarse-grained for quantifying beaver impacts.

Comparison of surveys of numerous Scottish lochs using this approach generally reveal only very modest changes in the vegetation of less impacted lakes over a time scale of decades (Willby *et al*., 2008). Consequently, it is suggested that this component of the baseline survey should receive proportionally less new effort and that more attention should be given to detailed quadrat surveys, as discussed below. It is also suggested that in future years base maps generated by this method are used as a template for mapping areas of beaver activity so that habitat preferences in relation to aquatic vegetation (structure and composition) can be explored effectively.

Generally it is considered that the SLSP approach is not well suited to intensive annual surveys of lakes. Raking is a rather destructive sampling method, especially in small oligotrophic water bodies, such as those found at Knapdale, and gaps in vegetation created by raking may be invaded by *Elodea canadensis*. If there is a need to undertake regular whole lake surveys, we would recommend that this is carried out by non destructive methods until the end of the trial. Aerial photography should also be considered as a cost effective alternative.

4.2 Site Condition Monitoring (SCM) Method

There would be advantages in harmonising the 2008 survey approach with the method developed by Gunn *et al.* (2004) for use in Site Condition Monitoring. However, the 2004 Knapdale SCM data that are available for comparison are more limited in extent and quality than the 2002 surveys by Murphy *et al*. (2002) and, to be of value, shoreline transects would need to be focused on areas of potential beaver activity. This would probably restrict the value of the existing SCM surveys. However, the combination and scale of perimeter, wader and boat transects, and their scale and detail of sampling, means that there are good prospects for detecting medium-scale impacts using this survey design. Sampling points would also be relatively easy to relocate. Because SCM will only consider a relatively small proportion of the water body, lower intensity impacts at a more general scale, or elsewhere in the loch, will be overlooked. The scale of sampling units may also be rather insensitive to very local, high intensity impacts attributable to beavers.

In developing SCM, it was recognised as an approach that may stimulate investigative monitoring of a different design that is tailored to the impact in question. The SCM protocol is also relatively time-consuming if undertaken fully (i.e. four sectors or more per lake, each with perimeter, wader and/or boat transects) and we consider that there are more cost-effective approaches for identifying and quantifying impacts of beavers and other potential changes in vegetation over the duration of the reintroduction trial. A related disadvantage is that the time required to complete each transect could cause an unacceptable level of disturbance to beavers if they are active in the vicinity of a given transect. We also consider that the SCM design is not suitable for intensive re-sampling, since the disturbance associated with potentially annual or biannual sampling of a section of shoreline could constitute a sufficiently important disturbance in its own right, to vegetation in a loch, especially one of low nutrient status.

4.3 Baseline

The baseline method (Murphy *et al*., 2002), using fixed transects and quadrats in each lake, has several attractions. These include the existence of a data-set from 2002 for all the primary lochs. Moreover, any change in vegetation between 2002 to 2008, in the absence of beavers, can be assessed against changes over the same length of time (2009-2014) in the presence of beavers. The scale of sampling unit (2m x 2m) is also compatible with the scale of impacts of beavers as found elsewhere (Jones *et al*., 2009).

Potentially, the baseline survey will be useful for detecting whole lake impacts of all levels of intensity. Such impacts are unlikely but possible during this study, e.g. as a result of invasive species or possibly, modification of water levels or riparian tree cover by beavers. This design, however, will be ineffective in registering local fine-grained impacts, since it is most unlikely that these will overlap with the locations of fixed quadrats, which, in the existing design, are very small in number.

Given that beavers appear to feed most actively in shallow water areas close to the bank and exhibit clear food preferences, we would suggest that the principles of the existing baseline survey design are reasonable. However, we foresee several simple improvements that could be implemented at little extra cost.

1. There should be a greater number of fixed transects per loch (a minimum of five unless the vegetation is very uniform). In the existing surveys (Murphy *et al*., 2002), some lochs had only two transects which is considered too low a number to detect future changes.
2. Surveys might consider attributes besides species composition. Since beavers often feed preferentially on the flowers or fruits of nymphaeids, it would be worth including counts of flowers, or rating evidence of damage when monitoring quadrats.
3. Surveys should consider the submerged aquatic zone, beyond the limits of beds of *Nymphaea* or other floating-leaved vegetation. This implies 4 rather than 3 quadrats per transect. This component of the survey is necessary to assess potential expansion of *Elodea* within or between water bodies. It may also be useful to assess possible impacts on isoetid vegetation which, being evergreen, might be utilised by

beavers during the winter, especially during periods of ice cover. We would note that the literature (Northcott, 1971, 1972; Simonsen, 1973) and our own observations at Bamff, Perthshire (Jones *et al*., 2009) indicate that beavers are most likely to have an impact on rhizomatous emergent or floating-leaved, as opposed to submerged macrophytes.

4. Quadrats should include stands of preferred food species, especially where these are of limited extent within a loch (e.g. *Menyanthes trifoliata*).
5. Mapping of vegetation polygons should be based on circumnavigating polygons in a boat and taking regular GPS readings to define the boundaries of each polygon. This is likely to be considerably more accurate and reproducible than sketches of the location of each polygon made from the boat or a fixed position on the bank. Digitising polygons which have been mapped visually is likely to give a false impression of the degree of geo referencing.
6. Maximum depths of colonisation by macrophytes should be recorded and used as an indicator of possible change in macrophyte cover. This may reflect changes in transparency due to phytoplankton, turbidity, or colour.

4.4 Other data

It appears that there have been no earlier systematic surveys of the vegetation of the primary and secondary lochs at Knapdale to consider in this study. For example, there is no evidence that the sites were visited in the early 1900s by the botanist George West, who prepared detailed accounts of the aquatic vegetation of the lochs of several areas of Scotland. Similarly, the botanist David Spence, who carried out detailed surveys of many lakes when preparing his account of the aquatic vegetation for "*The Vegetation of Scotland* "appears not to have visited any of these sites. There are earlier records in the BSBI Vascular Plant Database extending back to the 1950s for several of the rarer pondweed species in a number of the lochs, all of which still contain these species today. Generally, it is difficult to reconstruct vegetation data from isolated historical records, since earlier recording exhibits a number of forms of bias, most notably the exclusion of commoner species. For example, 1989 is the earliest record of *Nymphaea alba* in several lochs, despite this being probably the commonest and most conspicuous species in the Knapdale lochs.

4.5 Design of future surveys

Generally, we regard the baseline survey design, with the above refinements, as an acceptable design for monitoring future changes in vegetation against the backdrop of a beaver reintroduction. However, this design is definitely *not* optimal for subsequent purposes, if the desire is to demonstrate and *quantify* specific impacts of beavers on aquatic vegetation in a loch. This statement is made with the benefit of 5 years' experience of monitoring impacts of beavers on aquatic vegetation at a 5ha loch at Bamff in Perthshire that is qualitatively very similar to the most densely-vegetated of the Knapdale sites. Impacts of beavers on aquatic vegetation at this and other lochs have been small. However, given the criteria for success or failure of the reintroduction trial, we would argue that it is preferable to demonstrate and quantify such impacts properly, rather than failing to quantify them and consequently simply assuming that they do not exist. We are also aware of a significant recent paper (Parker *et al*., 2007) that demonstrated, using grazing exclosures, that native North American beavers can have significant impacts on aquatic plant biomass and composition through direct herbivory, quite independently of any ecosystem engineering effects. Consequently, we consider that the ability to measure impacts should be an important consideration in present and future survey designs.

The difficulty in designing a survey for the specific purposes of quantifying impacts is that, in our experience, the visible impacts of beavers on aquatic vegetation are very locally concentrated within small patches, which are themselves highly dispersed. It is very difficult to predict the location of these patches. At Bamff, Perthshire, a captive population of beavers within a very large natural enclosure (10 ha), established feeding platforms adjacent to the water's edge on floating rafts of fen vegetation. The positions of these patches bore no relation to the locations of beaver lodges. Visible impacts were confined to less than 10 feeding platforms and their immediate vicinity, with effects confined to patches of *c.* 2m x 2m. It was easy to identify preferred species from the remains of material at feeding platforms (typically rhizomes of *Menyanthes* or *Iris*, or, to a lesser extent, *Equisetum fluviatile* and *Carex rostrata*). Since these patches accounted for <0.01% of the cover of any one species, they amounted to a negligible effect on the site as a whole, or on the populations of individual species. This appears to be consistent with the minor impacts of the beaver population at another site in Scotland, Aigas, Beauly, where a demonstration project has monitored effects of beavers on the local environment over a three year period (http://www.aigas.co.uk/2009-Beaver-Diary-g.asp).

The 2002 baseline survey design would be extremely unlikely to detect such localised impacts, even with the modifications proposed for the 2008 season; in the very unlikely event that beaver impacts were to occur within one of the monitored quadrats, this would greatly exaggerate the true effect of beavers on the vegetation, if subsequently scaled-up to the water body level. On the other hand, it would be difficult to design a cost-effective sampling strategy for detecting such impacts, because an impractically large number of sampling points would be needed to ensure that some feeding sites were detected. Rapid sampling by fixed point photography of the water surface, at points that could be relocated by GPS, is the only viable technique that would enable sufficient sample points to be visited.

5. BASELINE SURVEY 2008 METHODS

The survey approach largely followed Lassiere (1998) and Murphy *et al.* (2002). Detailed vegetation mapping supported by transect surveys was undertaken only in the primary lochs. The surveys of the secondary lochs followed the method used by Lassiere (1998) and also adopted by Murphy *et al.* (2002) when surveying these water bodies.

In the present campaign, a boat was used to survey all but two of the lochs. Consequently access by boat was possible to all parts of most sites. The un-named Loch (North) was only accessible by boat with difficulty a canoe was hauled across the watershed between the un-named Loch and Creagmhor Loch. At Dubh Loch, use of a boat was not possible due to the density of surrounding trees and because the extensive raft of floating fen prevented safe boarding. At one of the secondary lochs, Lochan Duin, the condition of the access track prevented transport of a boat to the site, as a result of recent heavy rain. These were the two smallest lochs identified for survey and in both cases it is likely that a wader-based survey provided effective coverage.

A double-headed rake was used to sample fully-submerged vegetation, both within visually assessed polygons and at points where no vegetation was visible at the surface. Rake trawls revealed that submerged vegetation did not occur at depths below 6-7m. Zig-zagging across lochs, over areas deeper than 7m, was consequently inefficient and survey effort was therefore focused on the shallower parts of the littoral zone (<6m). When incident light conditions were favourable, a bathyscope or snorkel mask was used to view submerged vegetation *in situ*. The range of survey techniques applied was therefore somewhat dependent on the ability to use a boat, the weather conditions at the time of survey, the morphometry of each loch and the structure of its vegetation. The survey approaches used are summarised on a loch-specific basis in Table 3.

To map the vegetation at each site, individual polygons were identified that were characterised by the dominance of particular species or combinations of species. The identification of polygons is inevitably somewhat subjective and observer-specific, but macrophytes often form rather pure and discrete beds that are large enough to be represented spatially. In each loch, typically 20-30 polygons were identified, with the exception of the two smallest water bodies, Dubh Loch and un-named Loch (North). Each polygon was then mapped by circumnavigating the polygon and taking GPS readings every 5-10 metres, depending on the size of the polygon. The plant composition (as percentage cover), water depth and substrate were recorded for each polygon. In a small number of cases, substrate or depth could not be determined due to the density of vegetation, water colour, weather conditions or depth of overlying water. A total of 175 polygons were described and mapped across the eight primary lochs. When overlain on digital aerial photographs, 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. A significant mismatch in location and shape distortion was evident in the case of some polygons mapped in the 2002 surveys.

In the course of polygon mapping, representative locations were identified within each loch for detailed survey. At each location, a transect was established running perpendicular to the shore, from a point 2m inland out to a depth of c3-5m, or the maximum depth of macrophyte colonisation if less. Five transect lines were established in each loch, except in Dubh Loch, where three transects were considered adequate due to the uniformity of the vegetation, and in two of the smaller lochs, Fidhle and un-named Loch (North), where four transects provided adequate coverage. The transect lines in each loch followed the locations used by Murphy *et al.*, (2002), supplemented by transects at other locations. 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 at least 0.8 m projecting above the surface. These markers are conspicuous and should allow transect lines to be recognised from a distance, thus ensuring that they are avoided by other fieldworkers. Three more quadrats of the same size were positioned along the transect, one at the water's edge in the marginal zone, a second at a depth of 0.5-1m and the third at the end of the transect near, the end of the vegetated littoral. 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 % cover of all plants present in each quadrat was estimated by eye to the nearest 5%. Quadrats situated in shallow water (<0.5m) were viewed *in situ* from above. In deeper water, quadrats were generally viewed from a boat, using a snorkel mask if the bed was not clearly visible. To minimise disturbance to vegetation associated with transects, a rake was not used. At several sites, snorkelling along transects was used 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.

Table 3: Details of survey methods employed in 2008 and conditions at time of survey
1 Survey methods employed, where B - boat; R - rake; U - underwater viewing *in situ*; S - snorkelling
2 Good with still, strong incident overhead light, moderate with light wind, cloud and angled light, occasional light showers; poor - moderate wind, full cloud cover, intermittent heavy rain.

Loch name	**Date surveyed**	**Methods[1]**	**Survey conditions[2]**
Primary Lochs			
Dubh Loch	11.09.08	R,U	Good
Creagmhor Loch	11.09.08	B,R,U	Good-Moderate
Loch Barnluasgan	09.09.08	B, R	Poor
Loch Coille-Bharr	12.09.08	B,R,U,S	Good
Loch Fidhle	10.09.08	B,R,U,S	Moderate
Loch Linne	10.09.08	B,R,U,S	Moderate-Poor
Loch Losgunn	01.10.08	B,R,U	Good-Moderate
Un-named loch (N)	11.09.08	B,R	Good
Secondary Lochs			
Daill Loch	01.10.08	B,R	Moderate
Loch an Add	02.10.08	B,R	Moderate
Loch na Bric	01.10.08	B,R	Moderate-Poor
Lochan Duin	02.10.08	R,U,S	Good-Moderate

In most cases, it proved possible to locate the exact landward quadrat used by Murphy *et al.* (2002), but in some cases, despite careful searching, it was not possible to find the original permanent markers. In such cases, we used a point as close to the original line as possible, based on descriptions of the vegetation. Relocation of future quadrats should prove more straightforward, as more conspicuous markers were used. Even when the exact shoreline quadrat was pinpointed, it was difficult to be certain that the positions of the second and third quadrats overlapped exactly in 2002 and 2008. It will be difficult to ensure that subsequent surveys of aquatic vegetation overlap exactly with the quadrats used in 2008. However, all aquatic quadrats were located within large areas of homogenous vegetation, even with quadrat-specific GPS locations so a small drift in location between years is probably of little consequence. Murphy *et al.* (2002) established three quadrats on each transect line, and we added a fourth quadrat, to ensure adequate recording of vegetation in deeper water and to allow better detection of local recession in stand area due to herbivory.

In contrast to Murphy *et al.* (2002), no difficulties were experienced in the use of hand held GPS, spatial resolution being 6-10m. Recording of fixed-point features, such as milestones, road junctions and jetties, revealed that there was no systematic error in positioning when these co-ordinates were plotted in a GIS. The precision with which these features were relocated suggested that the true error was in fact likely to be nearer 1-2m. We also trialled the use of a Trimble GeoXT unit, which offers sub-metre accuracy in differential mode, but reception problems and the excessive time involved in collecting a single reading, which was not practical from a drifting boat, prevented effective use of this equipment.

At the conclusion 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 Lassiere (1998), as the basis for describing abundance (e.g. A = abundant). In line with previous surveys, DAFOR values were prefixed with ‘L’ for ‘locally’ to indicate when the particular level of abundance was associated with a limited area of the loch, rather than the whole water body. Plants which could not be identified directly in the field were retained and identified subsequently using Stewart & Church (1992), Preston (1995) or Rich & Jermy (1998). At each loch, the maximum depth of macrophyte colonisation was also noted, since this may have value as an indicator of future change in aquatic plant abundance.

The results of previous surveys were compared in terms of plant composition in the various lochs. Comparisons with previous surveys are made by assessing the detection rates of particular species, or in terms of 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*., 2008). 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 either on the average of the ranks of the taxa present, or an average that is weighted by the cover of each taxa.

6. RESULTS

6.1 Format of output

Detailed descriptions of individual lochs are given below. Each loch is also represented by a vegetation map showing individually numbered polygons identified during the 2008 survey. Clicking on these polygons in ArcGIS will bring up a list of their constituent plant species, plus depth and substrate characteristics if available. A hard copy of each vegetation map can be found in Appendix 1. The polygon information has been provided to SNH. Separate shape files are available for polygons, individual sampling points (where independent of polygons), transects points and photo locations. In preparing the GIS files we have noted that the supplied loch shoreline shape files can sometimes only be considered to provide a rough approximation of the true loch shoreline when overlain on geo-rectified aerial photographs.

Data collected at the fixed transects at each site co-ordinates of all polygons, points, transect quadrats and photographs have been supplied to SNH.

To ease the mapping of polygons in GIS and to assist the rapid interpretation of vegetation maps, the 175 individually delimited polygons have been classified manually into 16 different polygon types. These types are described in Table 4.

6.2 General description of primary lochs

The water bodies of Knapdale represent a complex of lakes that are typically elongate in shape and oriented south west to north east, following the direction of the local geology. The lochs are comparatively small (2-35 ha) yet some are surprisingly deep (~15m) relative to their areas (Appendix 1: Map 1 and 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 apex of the larger sites.

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. These species are widely underlain, or replaced in shallow water with coarse substrates, by the isoetids *Littorella uniflora* and *Lobelia dortmanna*. 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. x zizii*. 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 a rather open dispersed growth of *Phragmites australis*, *Scheonoplectus lacustris* and *Equisetum fluviatile,* which overlaps with the beds of floating-leaved species.

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* which are all well represented locally (Table 5). In drier areas the woodland understorey 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 upper catchment of all sites has been subject to extensive post-war planting with conifers, although these trees very rarely occur within 20m of the loch shore at all sites.

Table 4. Composition of vegetation in characteristic polygon types

Polygon name	Frequency	Description
Carex rostrata	11	stands dominated by *Carex rostrata* in which other species (e.g. *Littorella*, *Juncus bulbosus*, *Juncus articulatus*) may occur as subordinates
Cladium mariscus	8	stands dominated by *Cladium mariscus* with occasional very limited cover of other species (e.g. *Equisetum fluviatile*, *Nymphaea alba*)
Equisteum fluviatile	6	open stands dominated by *Equisetum fluviatile* sometimes with associated *N. alba, Schoenoplectus lacustris* or *Potamogeton natans*
Isoetid beds (high)	7	stands with >50% cover of *Littorella uniflora* and/or *Lobelia dortmanna*
Isoetid beds (low)	17	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)	16	stands with >50% cover of *N. alba* with limited cover of associates, most commonly *P. natans*, *S. lacustris* or *E. fluviatile*
Nymphaea alba (low)	14	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*
Other/mixed aquatic	13	stands dominated by species with very low overall frequency (e.g. *Nuphar pumila*, *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	19	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	12	range of fringing woody vegetation type in which *Betula pubescens* usually dominant or co-dominant
Phragmites australis	9	stands with cover dominated by *P. australis*, with *P. natans*, *L. uniflora* or *E. fluviatile* the most common associates
Potamogeton natans (high)	11	stands with >50% cover of *P. natans*, occasionally with sparse cover of *N. alba*
Potamogeton natans (low)	11	stands with <50% cover of *P. natans*, typically associated with sparse cover of *N. alba* and *S. lacustris*
Schoenoplectus lacustris	5	stands dominated by *S. lacustris* with occasional cover of *E. fluviatile* or *N. alba*
Sparganium angustifolium	5	stands dominated by *Sparganium angustifolium*, few associates (most commonly *Nuphar pumila*)
Submerged pondweeds	11	Beds of *Potamogeton praelongus*, *P. lucens*, *P.w x zizzii*, *P. perfoliatus*, sometimes mixed with *E. canadensis, Chara virgata* or *Myriophyllum alterniflorum*

Table 5. Percentage cover by woody species in 36 shoreline quadrats (2m x 2m) distributed around the eight primary lochs (Appendix 1: Map 1)

Species	**Total % cover**
Abies sp	10
Picea sitchensis	10
Ilex europaeus	20
Rhododendrum ponticum	20
Quercus sessilis	51
Fraxinus excelsior	80
Sorbus aucuparia	80
Corylus avellana	200
Salix spp	200
Alnus glutinosa	360
Betula pubsecens	640

Observations on the composition and distribution of vegetation at specific lochs are provided below. A representative photograph, showing a variety of features to which the text refers, is included in the account for each loch. These figures are collated at the end of the report. An over-view of the aquatic vegetation at all sites, based on DAFOR scores, can be found in Table 6. The composition of the emergent vegetation at all sites is summarised in Table 7. Table 8 includes information on the number of taxa and the Lake Macrophyte Nutrient Index for previous surveys of each water body. These have been calculated for comparative purposes.

6.3 Loch Barnluasgan

6.3.1 Vegetation

This is a moderately base-rich and relatively deep loch, and, in contrast to the other larger lochs, there are very few areas of coarser substrate. Consequently, isoetid taxa that are well represented at other sites (mainly *Littorella uniflora* and *Lobelia dortmanna*) are scarce in Barnluasgan. The Loch, however, supports a productive vegetation, and its apices and the bay in the north east corner have extensive beds of *Nymphaea alba*, *Potamogeton natans* and *Elodea canadensis*, locally intermixed with *Sparganium angustifolium* (Figure 2). Beyond the floating-leaved vegetation are large, submerged beds of *Potamogeton lucens* and *P. praelongus* in deeper water (3-5 m). See Appendix 1: Map 2.

The emergent vegetation is dominated by *Schoenoplectus lacustris* and *Phragmites australis*, the latter forming quite large stands in the north east corner of the Loch. *Equisetum fluviatile* occurs alongside *S. lacustris* at low density within the lily beds and there is a limited growth of *Carex rostrata* at a number of points around the shore.

Both this Loch and Coille-Bharr are more alkaline and lowland in character than several of the other lochs and this is reflected in the more diverse fen vegetation bordering part of the site. Thus, species such as *Angelica sylvestris*, *Caltha palustris*, *Filipendula ulmaria*, *Hydrocotyle vulgaris*, *Mentha aquatica*, *Lysimachia vulgaris*, *Phalaris arundinacea, Stachys palustris*, *Succisa pratensis* and *Valeriana officinalis* are all more common around the margins of these sites than any of the other lochs. Alder dominates the riparian zone at Barnluasgan and is commoner here than at any other site. Smaller areas of birch and willow are concentrated around the inflow and outflow streams.

6.3.2. Value as beaver habitat

This site offers suitable beaver habitat in terms of the abundance of aquatic vegetation. Depending on the rate of increase in population size and pattern of dispersal following their introduction, beavers would be expected to utilise the more secluded bay in the NE corner at some stage during the trial. Although there is an abundance of alder at this site the trees are predominantly large (dbh (diameter at breast height) > 25cm) and outwith the range of girths of 2 to 8 cm preferred by beavers, (Simonsen, 1973; Kindschy, 1985; Jones *et al*., 2003). There is public access around the whole perimeter of Banluasgan, but beavers are likely to habituate to human presence. Dogs may prove more of a deterrent, but are unlikely to overlap with areas utilised by beavers.

Table 6. Summary of aquatic vegetation composition at primary lochs in Knapdale 1989-2008

		Barnluasgan			**Coille-Bharr**			**Creagmhor**		**Dubh**	**Fidhle**		**Linne**			**Losgunn**		**Unnamed (N)**	
Taxa	sp_LMNI	29/6/1989	27/6/2002	9/9/2008	4/8/1989	27/6/2002	12/9/2008	25/6/2002	11/9/2008	11/9/2008	26/6/2002	10/9/2008	6/7/1989	26/6/2002	10/9/2008	26/6/2002	1/10/2008	25/6/2002	11/9/2008
Callitriche stagnalis	5.98			R															
Chara virgata	5.55	O		R			LA												
Elodea canadensis	7.14	LA	LF	LA		O	LA												
Filamentous algae	6.39			LF															
Fontinalis antipyretica	5.42	O		O									O	LF	O				
Isoetes lacustris	3.09	R		R		O	LF		LF				O	LF	R				
Juncus bulbosus	3.72							O	LF			LF			R	LF	LA		R
Lemna minor	7.58									O									
Littorella uniflora	4.70	F	O	O	F	F	A	LF	LF		LF	F	A	LA	A	F	LF		
Lobelia dortmanna	2.46	O		R	R		LF	LF	LF			R	A	LF	A	LF	LF		
Myriophyllum alterniflorum	4.54	O			F	F	LA	O	O			O	F	O	LF				
Nitella opaca/flexilis	5.60	O							R				R	R					
Nitella translucens	5.17				O												O		
Nuphar lutea	6.92	LA									LF	LF							
Nuphar pumila	5.33	O		R							?	LF					O		
Nuphar x spenneriana	5.61										?								
Nymphaea alba	5.54	A	A	A	O	LF	LA	LA	F	F	A	A	LA	LA	LA	A	LA	LA	LA
Poatmogeton alpinus	5.79				LF		LF												
Potamogeton berchtoldii	6.07			O	LF		O		O										
Potamogeton gramineus	5.51							O											
Potamogeton lucens	7.02		O?	LF	O	O	LF												
Potamogeton natans	5.16	A	A	A			F	A	O	A	LA	A	LA	LA	LA	A	A	A	A
Potamogeton obtusifolius	6.72				LF		R												
Potamogeton perfoliatus	5.83					O	LF		R										
Potamogeton polygonifolius	3.50											LF			O	O	LA		O
Potamogeton praelongus	5.77			LA	LF	LF	LF	LF					LA	?					
Potamogeton x zizzii	5.69	F			LF	?	LF		LF										
Sparganium angustifolium	3.65			LF		O	LF					R	O	O	O	LF	F		
Sparganium natans	4.84	O			LF	O													
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 indicate major discrepancies between surveys. ? indicates status or identity uncertain in 2002 surveys.

Table 7. Comparison of emergent plant composition at primary lochs in 2008

	Barnluasgan	**Coille-Bharr**	**Creagmhor**	**Dubh**	**Fidhle**	**Linne**	**Losgunn**	**Unnamed (N)**
Caltha palustris	R		R					
Carex lasiocarpa					LF	LF		
Carex paniculata				LA				
Carex rostrata	F	F		LF	F	F	F	LF
Cladium mariscus			LA	LA	LA	LA		
Eleocharis multicaulis			O		O	O	LF	
Eleocharis palustris	O	LF	R	R	R	O		
Equisetum fluviatile	F	F	O	A	O	F		O
Hydrocotyle vulgaris	R			O	R	R		
Iris pseudacorus	R	O						
Juncus acutiflorus	O		O		LF	O	R	
Juncus articulatus		R	R		O	R	LF	R
Juncus effusus	R	R				R	R	
Lythrum salicaria	R	O						
Mentha aquatica	R	R		LF				
Menyanthes trifoliata	LF	R		LF	O	O		R
Oenanthe crocata		O						
Phalaris arundinacea		LF				R		
Phragmites australis	LA	LA	LF				O	O
Potentilla palustris	O	R						
Ranunculus flammula	R				R	R		
Schoenoplectus lacustris	LA	LF	LA		LF	LF		
Scutellaria galericulata		O						
Sparganium erectum		R			R			
Sphagnum spp				O				
Veronica scutellata					R			

Table 8. Summary metrics for aquatic vegetation in primary lochs at Knapdale based on previous surveys

	Barnluasgan			Coille-Bharr			Creagmhor		Dubh	Fidhle		Linne			Losgunn		Unnamed (N)	
metric	29/6/1989	27/6/2002	9/9/2008	4/8/1989	27/6/2002	12/9/2008	25/6/2002	11/9/2008	11/9/2008	26/6/2002	10/9/2008	6/7/1989	26/6/2002	10/9/2008	26/6/2002	1/10/2008	25/6/2002	11/9/2008
No. TAXA	14	5	15	12	11	16	8	11	3	6	11	10	10	11	7	9	2	4
LMNI	5.34	5.75	5.50	5.42	5.16	5.26	4.77	4.71	5.82	5.52	4.72	4.50	4.57	4.16	4.40	4.38	5.32	4.80
Z max (m)			6			7			3		6			7		5		3

The LMNI value is the cover weighted mean of the species LMNI scores in Table 6 where R or ? =1, O=2, F=3 and A =4.
Zmax refers to the maximum depth of colonisation recorded in each loch, measured to the nearest metre. No data are available from previous surveys

6.4 Loch Coille-Bharr

6.4.1 Vegetation
Coille-Bharr is a large, deep, parallel-sided loch with steeply shelving margins around most of its shoreline. The loch is predominantly sparsely vegetated, but there is extensive aquatic and emergent vegetation at the south west end, and, to a lesser extent in the north east corner, especially where feeder streams have created areas of finer sediment. See Appendix 1: Maps 3-5.

In the large bay in the south west corner of Coille-Bharr, the aquatic vegetation is characterised by a matrix of *Nymphaea alba*, underlain by densely growing *Chara virgata* and patches of *Littorella* and *Lobelia*, interspersed with occasional beds of *Potamogeton lucens*, *Elodea canadensis*, *Potamogeton natans*, and *Sparganium angustifolium*. Due to the shallow water (generally 1-2m deep) and high degree of shelter, there is a fairly extensive growth of *Phragmites australis* around the margins, occasionally replaced by *Carex rostrata*, while beds of *Equisetum fluviatile* occur in open water (Figure 3). There is a steep shelf where this bay connects with the main loch. In this area there are large beds of *Potamogeton praelongus*, *P. perfoliatus* and *P. x zizii*, occasionally underlain by dense *Elodea canadensis*, typically growing in water 3-5m deep. In the far south west corner of Coille-Bharr there are smaller beds of *Phragmites* and *Schoenoplectus lacustris*, interspersed with *Littorella uniflora* and *Myriophyllum alterniflorum*, with larger beds of *Potamogeton perfoliatus*, *P. praelongus*, *P x zizii* and *Elodea canadensis* offshore. This assemblage is repeated in the north east corner of Coille-Bharr, covering a more restricted area. In the north east corner the sediments are sandier and there are also several extensive *Littorella uniflora* lawns, plus occasional patches of *Potamogeton alpinus* and marginal growth of *Phalaris arundinacea* and *Eleocharis palustris*. *Isoetes lacustris* is also locally frequent in shallow water, along the section of Loch directly south of the Tayvallich road.

With the exception of Barnluasgan, Coille-Bharr is more alkaline and lowland in character than the other lochs and this is reflected in the more diverse fen vegetation bordering parts of the site. Thus, species such as *Iris pseudacorus*, *Mentha aquatica*, *Lythrum salicaria*, *Oenanthe crocata* and *Phalaris arundinacea* are locally common around the margin, where there is a combination of shallow water and fine sediment. Alder dominates the riparian zone in the south west corner, but the over-hanging vegetation is more generally characterised by a mixture of birch and alder, with occasional willows, ash, rowan and oak.

6.4.2. Value as beaver habitat
The south west corner of Coille-Bharr provides good beaver habitat, since it is sheltered and densely vegetated with a range of preferred plant species, has a good depth of alder carr or *Phragmites* swamp around the margins, mostly low gradient banks, and public access is normally only taken by more committed walkers. The complexity of the shoreline offers secluded areas that would be ideal for lodge construction, as well as some very shallow, open water areas from which beavers might feed. The north east corner offers only limited suitable habitat and it seems most unlikely that beavers would regularly utilise any other parts of this loch.

6.5 Creagmhor Loch

6.5.1 Vegetation
Creagmhor is a medium-sized, low alkalinity, and relatively deep loch. Vegetation occurs around the margins, but is well developed only around the southernmost end of the loch, where *Nymphaea alba* and *Potamogeton natans* beds occur (Appendix 1: Map 6). The substrate is typically more gravelly at this site and there is a correspondingly greater relative importance here of the major isoetid species *Littorella uniflora*, *Lobelia dortmanna* and

Isoetes lacustris. The only other notable feature is a large bed of *Potamogeton x zizii* on the outer face of a stand of *Schoenoplectus lacustris,* in the northern part of the loch. Generally, the northern shoreline is steep and rocky and most development of emergent vegetation occurs along the south west shore where narrow belts of low density *Phragmites australis* and *S. lacustris* occur at low population density. There is a single large stand of *Cladium mariscus* in the south west corner of the loch. See Figure 4.

The woody vegetation around this site is rather heavily dominated by birch, although rowan and willow are both present, with alder in smaller quantities. This is the only site where *Rhododendron* was found. The understorey is typically dominated by a matrix of *Molinia*, with *Erica tetralix*, *Myrica* and *Sphagnum* replaced by *Pteridium*, *Calluna* and *Vaccinium* in drier areas.

6.5.2 Value as beaver habitat

Creagmhor is a rather unproductive loch and the areas most readily suited to feeding and lodge construction appear to be in the southernmost corner. Conceivably, beavers might move between this water body and the smaller un-named Loch (North) directly to the west. Creagmhor is largely undisturbed, access being via a locked gate.

6.6 Dubh Loch

6.6.1 Vegetation
This is a small, relatively shallow water body, located just to the east of Coille-Bharr and is heavily shaded by a steep slope on its south east side. Dubh Loch was difficult to survey safely, due to the extent of floating mire and density of tree cover, which prevented the use of a boat. It was therefore circumnavigated, taking regular rake throws at points where open water could be accessed safely.

Dubh Loch is quite unlike the other primary lochs. It represents a classical hydrosere, being surrounded by wet alder and willow woodland, followed by *Carex paniculata* and *Cladium mariscus* swamp, *Equisetum fluviatile* swamp, *Nymphaea alba* and finally *Potamogeton natans* beds (Figure 5). There is extensive floating mire development at the north and south ends, including large growths of *Equisetum fluviatile*, *Carex rostrata* and *Menyanthes*. These are gradually replaced by encroaching alder and willow carr, beneath which *Carex paniculata* is dominant (Appendix 1: Map 7).

Given its small size this is a surprisingly deep loch water depth descending to >3m within 10m of the banks. Consequently, the bands of marginal vegetation are sharply delimited. Submerged aquatic vegetation seems to very limited, due perhaps to the slight peatiness of the water, instability of the substrate, and shading by fringing trees, or the steep wooded scarp to the immediate east of the site. At this site, some ponding has occurred in the fringing woodland, following repairs to the forestry track that runs along part of the western boundary.

6.6.2. Value as beaver habitat
This site offers ideal beaver habitat due to the combination of banks of low gradient, well wooded margins, wet woodland and suitable macrophyte species for grazing, as well as being relatively undisturbed. However, the site may be too small on its own to support a territory. Dubh Loch has the potential to be used by beavers commuting from the south east end of Coille-Bharr.

6.7 Loch Fidhle

6.7.1 Vegetation
This is a well-vegetated loch with shallow margins and extensive emergent and floating leaved vegetation, except on the eastern shore, where the banks are rocky and drop sharply into deep water. The vegetation is characterised by an abundance of *Nymphaea alba* and *Potamogeton natans*, locally interspersed with *Nuphar pumila* and *Nuphar lutea*. Other aquatic species are relatively uncommon; there is a limited coverage of the main isoetid species, as at Barnluasgan, while both *Juncus bulbosus* and *Myriophyllum alterniflorum* are locally frequent or occasional. In the south west part of Fidhle, there are large areas of emergent vegetation, including beds of *Cladium mariscus* and smaller stands of *Carex rostrata*, *Carex lasiocarpa* and *Eleocharis multicaulis* (Figure 6). *Schoenoplectus lacustris* is intermixed with the beds of *N. alba* and *P. natans* in the north of the site. See Appendix 1: Map 8.

Marginal vegetation is dominated by wet acid mire with *Molinia*, *Myrica* and *Sphagnum* species being most characteristic. Heavily wooded margins overhang the eastern shore, with sessile oak and birch being dominant.

6.7.2 Value as beaver habitat
There is extensive aquatic and emergent vegetation with gently shelving shorelines and soft banks around approximately two thirds of the loch. However, the reduced proximity and density of trees results in poorer cover along the margins. There is a very steep scarp to the eastern shore and it seems unlikely that beavers would move readily between Fidhle and either the un-named loch (North) or Creagmhor to the east.

6.8 Loch Linne

6.8.1 Vegetation
Linne is a rather large and predominantly deep loch of low alkalinity that shares some of the features of Coille-Bharr in terms of shoreline characteristics and distribution of vegetation (Appendix 1: Maps 9-10). The only extensive aquatic vegetation occurs in the southern corner near the landing stage and in the bay to the south of this around the loch outflow. There are smaller areas of aquatic vegetation at the northern apex and at several points along the eastern shore where Linne connects with Loch Fidhle. The aquatic vegetation typically comprises large beds of *Nymphaea alba* and *Potamogeton natans,* underlain by a vigorous growth of *Lobelia dortmanna*, *Littorella uniflora*, and occasionally *Myriophyllum alterniflorum*. Emergent vegetation is characterised by several small beds of *Cladium masriscus* along sheltered parts of the eastern shore, and small sedge swamp in the outflow bay, while *Equisetum fluviatile* and *Schoenoplectus lacustris* form open stands overlapping with *N. alba* and *P. natans* in the area around the landing stage, and intermittently along the eastern shore and northerly apex of the loch (Figure 7).

The fringing woodland at this site is relatively diverse and extensive, including hazel, sessile oak, willows, ash and rowan, amongst a matrix of birch. There are small numbers of willow and alder around the outflow. The banks are generally steep and rocky and the understorey is correspondingly more typical of western oak woods with a range of ferns and bryophyte species interspersed with *Molinia*.

6.8.2 Value as beaver habitat
Linne is a rather unproductive site in terms of its aquatic vegetation. The southernmost areas offer potentially suitable habitat and feeding for beavers, with a range of preferred tree

species close to the banks. However, the banks are predominantly rather steep and rocky, and most of the trees are mature and potentially outside the range that beavers will readily fell. The watershed which separates Linne from Barnluasgan and Coille-Bharr to the south and west, is very steep and densely wooded. Movement of animals between Fidhle and the southernmost parts of Linne therefore seems most probable.

6.9 Loch Losgunn

6.6.1 Vegetation
There is extensive growth of *Potamogeton natans* and *Nymphaea alba* around most of the site, except on parts of the north west shore where the banks are comprised of rock and dip steeply. Less typical are the large beds of *Potamogeton polygonifolius* and extensive growth of *Juncus bulbosus,* which are consistent with the very low alkalinity of this loch. Losgunn is superficially most similar to the smaller un named Loch (North) and has large areas of *N. alba* in its southern corner that are undergoing terrestrialisation and transition into floating mire (Figure 8). However, frequent cover of both *Littorella uniflora*, *Lobelia dortmanna* and *Sparganium angustifolium* are features of the larger deeper lochs at Knapdale, such as Coille-Bharr. See Appendix 1: Map 11.

Emergent vegetation is largely limited to beds of *Carex rostrata*, plus smaller patches of *Eleocharis multicaulis* and *Juncus articulatus*, with *Phragmites australis* and *Equisetum fluviatile* scarce or absent, respectively.

The banks are generally low lying and wooded with birch, willow and alder, and have an understorey dominated by mire forming species such as *Molinia*, *Myrica*, *Calluna* and *Sphagnum*.

6.6.2. Value as beaver habitat
Losgunn is fairly small and rather isolated from the other primary lochs, and is set within rather dense forestry. The extent of emergent vegetation is very limited. However, Losgunn is very little disturbed and provides low gradient banks, extensive cover of macrophytes and easy access to preferred tree species. Depending upon the movements of beavers post-release, or their dispersal patterns once population sizes have increased, it seems likely that animals would utilise this site.

6.10 Un-named loch (North)

6.10.1 Aquatic vegetation
This loch lies in a shallow depression between Creagmhor and Fidhle and drains via a cascade into Fidhle. The site has little in common with its most adjacent lochs, being shallow, slightly turbid and heavily-dominated by *Potamogeton natans*, and is most similar to Losgunn in terms of its vegetation. *Nymphaea alba* is also common, but, as with Losgunn, the stands in the south of the site are undergoing terrestrialisation, with peat mats bound by floating *N. alba* rhizomes exhibiting a transition to floating mire (Figure 9).

Coverage of substrate by emergent species is mainly confined to a rather dispersed growth of *Equisetum fluviatile* and *Phragmites australis*, plus small stands of *Carex rostrata*. See Appendix 1, Map 12.

6.10.2. Value as beaver habitat
This small, relatively undisturbed would support beavers. The soft banks of low gradient are suitable for tunnelling and there is an ample supply of young birch and willow close to the water's edge that could be used for feeding and lodge construction.

6.11 Secondary lochs

The four secondary lochs are represented by a series of interconnected reservoirs, managed by British Waterways, for the operation of the Crinan Canal. Three of these sites were surveyed by boat. The two larger sites are almost devoid of aquatic vegetation, but Lochan Duin and Loch na Bric support locally extensive and diverse aquatic vegetation. A detailed description of each loch is provided below. The aquatic vegetation of these sites is tabulated in Table 9 and can be compared with data from the 2002 and 1989 surveys of the same sites. Table 10 summarises the emergent vegetation of the secondary lochs.

6.12 Daill Loch

Daill Loch supports very limited aquatic vegetation. Plants are confined to small patches of fine sediment associated with sheltered bays and inlets around the shoreline. Outwith these locations, vegetation is absent, due to a combination of tree shading, exposure, steep littoral slope and very coarse substrates. Where it does occur, the vegetation is typically restricted to the prostrate form of *Juncus bulbosus*, that is characteristic of fluctuating water levels in shallow littoral areas. This is interspersed with emergent patches of *Eleocharis palustris* or *E. multicaulis*, *Juncus articulatus* and *Carex rostrata*. Commoner associates include *Littorella uniflora*, *Ranunculus flammula*, *Lythrum portula*, *Hydrocotyle vulgaris* and *Persicaria hydropiper*. The southern extreme of the southerly arm harbours a more extensive deposit of finer sediment, on which there is a limited growth of *Callitriche hamulata*, *Myriophyllum alterniflorum*, *Potamogeton alpinus* and *P. praelongus*. The southern basin is surrounded by dense, mature, conifer forest, although this is generally set well back from the shoreline (Figure 10). Around this basin, and along most of the southern shore of the main south west to north east axis of the loch, the banks are low and somewhat undercut; *Calluna*, *Pteridium* and *Vaccinium* dominate the adjacent vegetation, being locally replaced by *Myrica* and *Molinia* in less well drained areas. The northern shore and the south western end of the main basin support good riparian woodland, in which several *Salix* species are well-represented amongst *Betula pubsecens*, *Sorbus aucuparia* and *Corylus avellana*. The growth of willow at this site, which will certainly be favoured by the fluctuating water levels associated with reservoir operation, could make Daill Loch more attractive to beavers, despite the very restricted growth of aquatic plants.

6.13 Loch an Add

Loch an Add is a large, deep, elongate reservoir. On the gentler slopes of the northern shore, the margins are well-vegetated by a range of small herbs (e.g. *Agrostis stolonifera*, *Potentilla anserina* and *Ranunculus flammula*) that are tolerant of water level fluctuations. This drawdown zone is backed by *Pteridium*, *Calluna* and *Myrica*. Larger emergent species are absent. The majority of southern shore is, however, characterised by very steep, unvegetated rock, topped locally by willows and mature conifers (Figure 11). As is typical of reservoirs, the riparian zone and water body are largely disconnected and the littoral zone is extremely sparsely vegetated. The only area of any ecological interest is at the far southern end where there is an area of formerly inundated mire (equivalent to *c*. 5% of the total reservoir area), with pools and small flushes. The mire is dominated by *Carex rostrata*, *Potentilla palustris*, and *Carex nigra*, with smaller areas of *Hydrocotyle vulgaris*, *Ranunculus flammula*, *Eleocharis palustris*, *Viola palustris*, *Juncus articulatus* and *Sphagnum* spp. The open water areas are dominated by *Potamogeton natans,* plus a sparse coverage of *Menyanthes trifoliata*, *Callitriche stagnalis* and *Sparganium angustifolium*. Following a substantial drop in historic water level, this southern basin is now only connected to the main reservoir by a narrow incised channel.

It appears, from the large number of incised streams entering the reservoir, and a belt of drowned and now dead trees, that the operating water level of Loch an Add was changed significantly, to a level about 2-3m lower than its original, perhaps 20 years ago.

6.14 Lochan Duin

This is a small, shallow reservoir with gently shelving shores around two thirds of its perimeter (Figure 11). Aquatic vegetation is well developed at this site, with a mixture of *Myriophyllum alterniflorum*, *Littorella uniflora*, *Lobelia dortmanna* and *Potamogeton perfoliatus* well-represented in shallow water around most of the site, and *Isoetes lacustris*, *Nitella opaca* and large beds of *Chara virgata* in deeper water. In the west and south there are several large beds of *Potamogeton natans*, a large bed of *Nuphar x spenneriana* and dispersed patches of *Nuphar pumila*. There are extensive beds of *Chara virgata* in the south western corner of the loch. Several large patches of *Potamogeton alpinus* occur in shallow water in the south, as well as near the dam and in the outflow channel. Fragments of *Potamogeton praelongus* were found in drift near the dam, but without the aid of a boat, no beds of this species could be located.

Emergent vegetation is rather limited in extent and is confined to some small beds of *Equisetum fluviatile*, *Eleocharis palustris* and *Carex rostrata* on the south western and southern shore. Banks are rather steep and densely wooded with mature conifers, although there are some small areas of birch, with occasional willow and alder. The understorey is dominated by *Calluna*, *Pteridium* and *Vaccinium myrtilus*.

Lochan Duin is a rather small, isolated and undisturbed site that shows little evidence of water level fluctuation, or management as a reservoir, despite being an obvious impoundment. Given these features, plus the extent of aquatic vegetation, and the proximity of Lochan Duin to the primary lochs (Figure 1), it seems possible that beavers will use this site. The extensive conifer forestry that surrounds it, and comes close to the water’s edge in many places, is a negative feature, yet young birch, alder and willow are also present and there are some good stands of willow on the outflow stream near Dunans, about 500 m downstream.

6.15 Loch na Bric

Aquatic vegetation is largely restricted to sandy sediment along the northern and north eastern shores and to peaty sediments at the southern end of Loch na Bric. Minor patches occur elsewhere, mainly in the bay adjoining the dam. Approximately 70% of the shoreline is composed of steep, bare rock exposures, with very coarse substrates and deep water at their immediate base. Despite this, the aquatic vegetation is surprisingly diverse, featuring no fewer than six pondweed species. The most characteristic features of the aquatic vegetation are a very vigorous shallow water growth of *Potamogeton gramineus*, mainly around the northern end of the loch, and a large bed of *Nuphar* x *spenneriana* at the southern end, amongst which a range of broad leaved pondweeds occur. At the time of survey, Loch na Bric had been lowered by 3 metres for the previous four months, to allow repairs to the dam wall. Consequently, the extent of aquatic vegetation may have been somewhat higher than normal. Due to the lowered water level, drawdown zone vegetation was well-established at each end of the Loch (Figure 13). These areas featured extensive growths of *Hydrocotyle*, *Ranunuclus flammula*, *Littorella uniflora*, *Juncus bulbosus*, *Eleocharis palustris*, *Equisetum fluviatile* and *E. arvense*. The proximity of woody vegetation is restricted by the nature of the banks, which are usually topped by a mix of *Betula pubescens* and *Sorbus aucuparia*. However, as with Daill Loch, willow is locally prominent on the shore where the gradient is reduced, and is more abundant at Loch na Bric than at most of the primary lochs.

Table 9. Summary of aquatic vegetation composition in secondary lochs in Knapdale 1989, 2002 and 2008.

	Daill Loch		Loch an Add		Loch na Bric			Lochan Duin		
	28/6/2002	1/10/2008	28/6/2002	2/10/2008	26/6/1989	28/6/2002	1/10/2008	26/6/1989	28/6/2002	2/10/2008
Callitriche hamulata		R								
Callitriche stagnalis				R						
Chara virgata									O	LA
Fontinalis antipyretica	O	O								
Isoetes lacustris									O	LF
Juncus bulbosus		O		LO		O	O			R
Littorella uniflora		O					LF	A/D	F	
Lobelia dortmanna								A/D	LF	F
Lythrum portula		LF								
Myriophyllum alterniflorum		O					LF	F	O	F
Nitella opaca								R		LF
Nuphar lutea					LA	R				R
Nuphar pumila										O
Nuphar x spenneriana							LF	LA	LA	LF
Nymphaea alba								LA		
Potamogeton alpinus		R					O			O
Potamogeton berchtoldii							O			
Potamogeton gramineus						R	LA		O	
Potamogeton natans				LO		R	O	LA	F	LF
Potamogeton perfoliatus							R		R	F
Potamogeton praelongus		R					O		O	R
Sparganium angustifolium	O	R		R		O	R	O		
Utricularia intermedia		R								

Note: no aquatic vegetation was recorded in Loch an Add in 2002.

Table 10. Summary of emergent vegetation in secondary lochs in Knapdale, 1989, 2002 and 2008

	Daill		**an Add**		**na Bric**			**Duin**		
	28/6/2002	1/10/2008	28/6/2002	2/10/2008	26/6/1989	28/6/2002	1/10/2008	26/6/1989	28/6/2002	2/10/2008
Carex nigra				LF						
Carex rostrata		O		LF			LF			O
Eleocharis multicaulis		R								
Eleocharis palustris		O		LO			LF			R
Equisetum fluviatile		O					LF			LA
Glyceria fluitans		O		R						
Hydrocotyle vulgaris		LF		LO			LO			
Juncus articulatus				LO						R
Menyanthes trifoliata				LO						
Potentilla palustris				LF						
Ranunculus flammula		LF		LO			LF			
Sphagnum auriculatum				LF						
Viola palustris				LO						

Note: no records of emergent vegetation appear to have been made in earlier surveys at these sites

7. DISCUSSION

7.1 Sources of variability and comparison with earlier surveys

The aquatic plant survey data of 2008 are summarised as DAFOR values in whole-lake form in Table 4, and can be compared with the results of previous surveys. Major differences between these surveys are highlighted. The extent to which individual macrophyte surveys can be compared, when undertaken by different surveyors, with different survey effort or methods, and for different purposes, is highly questionable, mainly due to detection bias and differences in identification. Several factors merit particular attention, due to their effect on detection rates.

- Boats were used almost universally in the 2008 survey and the approach to polygon mapping meant that surveys of individual lakes probably took longer to complete than in previous years. The number of taxa recorded in the 2008 surveys was in all cases higher for each lake than in the previous three surveys. The consistent use of a boat undoubtedly enabled more thorough surveying to be carried out in 2008.

- Weather conditions at the time of survey will certainly have a significant effect on the ability to detect deeper water species, regardless of the use of underwater viewing equipment or rakes. Still conditions with strong sunlight are vastly superior to cloudy, wet and windy weather for lake macrophyte surveys. Thus, data on submerged plants in a lake that were collected by experienced teams on consecutive days may be difficult to compare if conditions at the time of survey were dissimilar. Hence it is difficult to say with confidence that *Isoetes lacustris*, found at Coille-Bharr in 2002 and 2008, but not recorded there in 1989, was actually absent in that year (it seems very unlikely that this would be the case). Similarly, in 2008, we were unable to locate *Potamogeton praelongus* in either Creagmhor or Linne, where it had been found in previous years, yet we found large beds of this species in Barnluasgan, where it was not previously recorded. It would be impossible to say with any certainty that *P. praelongus* was absent from Creagmhor or Linne in 2008, or was absent from Barnluasgan in 1989 and 2002.

- Carrying out transect surveys with intensive recording at regular points, introduces a different type of survey approach that may lead to the detection of locally distributed species, not revealed by more general surveys. Certainly, *Utricularia intermedia* agg, which was not found elsewhere, or in any previous surveys of the Knapdale lochs, would not have been located at Lochs Linne and Fidhle, if quadrat surveys using snorkel diving had not been carried out.

- There is an element of chance in the detection of less common submerged species that are not visible from a boat, since their detection is entirely dependent on the random placement of a grapnel in the right place. Again, the use of a boat probably enables the sampling of a wider range of habitats using a rake, than can be accomplished from the shore alone using a rake.

- Some of the differences between the surveys may reflect identification errors. In the early period of the NCC Loch Surveys, *Sparganium* species were frequently aggregated or confused. The presence of *Sparganium natans* in either Barnluasgan or Coille-Bharr, both of which supported locally frequent

S. angustifolium in 2008, must therefore be considered doubtful. The other major identification issues surround separation of the hybrid lily *Nuphar x spenneriana* from either *N. lutea* or *N. pumila*, which cannot always be done reliably, and the separation of *Potamogeton x zizii* from *P. lucens* and *P. gramineus*. We did not find *P. x zizii* in Barnluasgan, where it was recorded in 1989, although large beds of classic *P. lucens* were found there. Since the *P. x zizii* in Barnluasgan was confirmed by an authority on macrophytes, C. D. Preston, we must assume that we were simply unable to find this plant. However, it was present in abundance at the southern end of Coille-Bharr in 2008, where it was also found in 1989. The *P. gramineus* record, from Creagmhor in 2002, is almost certainly also an error for *P x zizii*.

Accepting that direct comparisons of the presence or absence of individual species are unlikely to be meaningful, it may be possible to assess the vegetation instead on the basis of simple metrics based, for example, on nutrient affinity. The calculation of a Lake Macrophyte Nutrient Index (LMNI) score for each survey of each water body facilitates a comparison of the vegetation between lochs and surveys. The range of LMNI values in Table 8 (*c*.4.5-5.5) are typical of what would be expected of low to moderate alkalinity lochs with low levels of anthropogenic enrichment. The higher LMNI values recorded in Barnluasgan and Coille-Bharr are consistent with the higher alkalinity at these sites and should not be interpreted as evidence of increased impact. Differences between surveys of the same water body are generally small (<0.5 LMNI units) and, when larger than this (e.g. Fidhle and un-named Loch (N)) can be explained by differences in survey effort and the number of taxa consequently recorded. Therefore, applying this approach offers no evidence of directional changes in the vegetation at any site in the last 20 years that might be indicative of increasing anthropogenic pressure, other than invasion of two sites by *Elodea canadensis*.

7.2 Current status of *Elodea canadensis*

Elodea canadensis is currently established in two Knapdale lochs, Barnluasgan and Coille-Bharr, and may have expanded its distribution within the latter site, since it was found there in 2002. Although the presence of *E. canadensis* at these sites is not desirable, it currently appears to be relatively benign and it is difficult to envisage that either site supported a significantly different flora prior to 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 Barnluasgan or Coille-Bharr. Dubh Loch is perhaps the most vulnerable site, being located in close proximity to Coille-Bharr. At the current time, the most likely agent of spread of *Elodea* to the other lochs (excluding the un-fished Dubh Loch) 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, *Elodea* was absent from all the secondary lochs, several of which are also fished regularly.

Beavers might conceivably increase the risk of spread of *Elodea* if feeding activity leads to greater fragmentation of plants, or if they commute regularly between several sites, but the risk would appear to be very small and is probably no greater than that associated with potential dispersal by water birds. The study by Parker *et al.* (2007) indicates that beavers may, in fact, increase control of invasive non-native species through selective herbivory.

7.3 Review of cost effectiveness of survey techniques in light of 2008 survey

All but two of the present surveys involved the use of a boat (Canadian canoe). This was both an efficient way of undertaking the surveys and also of moving safely and quickly around each site between fixed transects, and enabled a more thorough survey to be conducted. Consequently, a boat should be used in all future surveys at these sites for the purposes of monitoring. Our initial view was that a boat would not be necessary for repeating surveys of fixed transects. The use of a boat is now recommended, because it allows transects to be accessed more quickly and minimises damage to vegetation during surveying. Disturbance to beavers is probably also reduced.

Full vegetation surveys, including mapping of individual polygons, are relatively time consuming, requiring 4-6 man days per water body for preparation, survey and data processing, depending on the size and complexity of the lake. It seems inappropriate to invest significant resources in the future in regular surveys of this type, since any impacts detectable at this scale would surely also be registered at the scale of individual transects. Moreover, the limits of accuracy of GPS in mapping polygons (~ ± 6m) imply that a reasonable time-frame should be provided before resurvey, in order to allow for possible changes that are outside instrument variability. Instead, we would suggest that a repeat survey, following this protocol, is undertaken at the conclusion of the trial, again in September, and that results are used for comparison with the baseline data. Ideally, this should be carried out by the same personnel, to minimise the effects of observer-based variability (e.g. in delineating or classifying polygons), although the method might prove robust enough not to necessitate this. Mapping of vegetation simply by eye should be avoided, since it generates a distorted view of the true shape and extent of macrophyte beds. Digitising hand-drawn maps gives a false impression of the degree of geo-referencing.

Future work on the effects of beavers on macrophytes is probably best undertaken in September, because September represents the end of the growing season and impacts of beavers are most likely to be detectable, and to synchronise with the present study. By September potentially beavers will have had 4-5 months to feed on macrophytes, while the growth rate of macrophytes is generally reduced after mid-summer; beaver effects are therefore unlikely to be obscured by rapid regrowth, as they might be early in the season. The only obvious disadvantage is that selective feeding, e.g. on flowers, which might occur earlier in the growing season, will be overlooked.

In our surveys, submerged vegetation was restricted to depths of 6-7m. In some sites, the maximum depth colonised was 3m, even though the whole water body was within the maximum rooting depth range. The deeper sites are slightly coloured and several of the shallower sites were mildly turbid, due to sediment re-suspension. We recommend that future surveys are restricted to the ittoral area where water depths are <7m and that time should not be spent undertaking long trawls of deeper areas, where plants are very unlikely to be found.

Aerial photography campaigns could provide a rapid and accurate way of collecting data on large-scale distribution of vegetation in the future and would allow changes, e.g. in the extent of individual macrophyte beds, to be quantified. A single campaign conducted mid-way through the trial may prove valuable. However, it is important to stress that aerial photography will require ground-truthing. Even at the height of the growing season, aerial photographs may offer very little information on submerged vegetation, while overhanging tree cover is likely to restrict the view of shallow water vegetation. The potential role of aerial photography should be reviewed at the end of the first growing season when the distribution and potential effects of beavers at Knapdale are more apparent.

Re-surveys of quadrats located along individual transect lines within each loch could be accomplished fairly quickly (perhaps 4 days' fieldwork for all primary lochs) and there would be minimal costs associated with processing of data. Most quadrats surveyed in 2002 could be located, using a combination of GPS and vegetation data as a guide to finding the permanent markers. More conspicuous markers were used to represent the shoreward end of the 2008 transects, as significant time was expended in searching for some of the original 2002 transects. These markers will also allow other fieldworkers to be alerted to the presence of transect lines, thereby ensuring that these are not subject to accidental trampling. We would suggest that surveys of the new fixed quadrats are undertaken annually, at the same time each year, for the next five years. Even if none of these quadrat points are specifically affected by beavers, this will yield important baseline data on inter-annual fluctuations in vegetation, which can be used to assess the relative significance of change in vegetation at locations where beavers have been active. We suggest that once the beavers have become established and local preferences are clear, the same design of transect and quadrat sampling could be implemented to ensure that some locations are 'captured' in which beavers are active. This might include a more detailed assessment of plant remnants at feeding platforms, in order to provide an indication of what beavers at Knapdale are primarily feeding on. The use of a boat would expedite such a study. Other survey points could then be located at increasing distance from each feeding point, in order to capture a gradient of grazing intensity.

We also advise that towards the end of the 2009 growing season, short surveys are undertaken of three additional lochs, which are on the periphery of the reintroduction area, to check whether beavers are using these. Casual observations made in 2002 indicated that both Lochan Buic, an un-named Loch to the south, and Loch McKay provided areas of suitable habitat for beavers. These three lochs are as close to several of the primary lochs as some of the secondary lochs visited in 2008. The small pool 400m south of Losgunn, which is marked by a ford, might also repay further investigation following the release.

7.4 Potential effects of beavers on aquatic vegetation at Knapdale

The potential effects of beavers on aquatic vegetation can be considered in terms of the direct effects arising from herbivory, or the indirect effects associated with habitat modification (principally change in loch water level and reduced shading of margins due to tree felling). Regular monitoring of water chemistry in the Knapdale lochs will be undertaken by SEPA, for the duration of the trial (covering pH, alkalinity, conductivity, ammonia, nitrite, nitrate, total and dissolved reactive phosphorus, and chlorophyll a). Water level data will be available for all primary lochs via automatic recorders. The environmental data will be used to interpret any changes in vegetation that occur during the trial, and to assist in discriminating between changes that are a response to the activities of beavers, and those that may have occurred due to external pressures.

The Knapdale lochs contain significant quantities of a range of large rhizomatous emergent and floating-leaved macrophytes, for which beavers display strong dietary preferences. These include *Nymphaea alba*, *Equisetum fluviatile*, *Schoenoplectus lacustris*, *Menyanthes trifoliata* and various large *Carex* species. Although not specifically recorded, it seems likely that beavers would also feed upon *Cladium* *mariscus*. All these species have a long history in Scotland and have coexisted with beavers for millennia prior to their extinction. Beavers are also known specifically to favour water bodies with extensive nymphaeid vegetation. The populations of all these species at Knapdale are sufficiently large that herbivory by beavers could not lead to the complete loss of any species, at either the regional or local level. However, herbivory represents a disturbance on top of that due to the stresses imposed on plants caused by pre-existing factors, such as wave action. In naturally unproductive lakes, such as those at Knapdale, herbivory might therefore be expected to lead to a localised reduction in the cover of some of the preferred dominant plant species. The expectation is that this would occur without changing the overall appearance or character of the vegetation as a whole.

An additional observation made at the time of survey was that some emergent species that might be expected to be consumed by beavers, notably *Schoenoplectus lacustris* and *Equisetum fluviatile,* are important in terms of 'engineering' hydraulically sheltered habitats that are subsequently colonised by a range of isoetid species and pondweeds. A reduction in the extent of some large, open water emergent species might, therefore, have knock-on effects on other species that are not directly consumed. On the other hand, this might be offset by the effects of caching of felled timber by beavers that may generate similarly sheltered habitat to that afforded currently by emergent plants. *Phragmites australis* can also act in a similar way to *S. lacustris* and *E. fluviatile* but the stems and leaves of *P. australis* are more strongly lignified and this species is reportedly rarely consumed by beavers (F. Rosell, personal communication).

The morphometry of the Knapdale lochs and the gradients of their outflows are such that the potential to cause significant (>20cm) increases in loch water levels through damming would appear to be very limited. It is also 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. Even outwith the SAC, the dominant aquatic plant species at all sites are all capable of accommodating a water level increase of this degree and, given the composition of trees closest to the water's edge, significant dieback due to waterlogging stress seems very unlikely. It is more likely that beavers will dam the small forested streams where these run through areas of more extensive young willow carr.

Tree felling around the periphery of the lochs themselves may result in local changes due to reductions in shading (unless trees are incompletely felled). Much of the tree cover within 10m of the loch margins is mature and outwith the the preferred felling size range of beavers (i.e. dbh of 2-8cm). Many of the alder, rowan and ash trees are very large (i.e. dbh >25cm) and it seems likely that beavers will preferentially fell generally smaller birch and willows. Nevertheless, some attempted felling of some larger trees seems likely. There is the potential to modify aquatic plant habitat (as well as provide submerged structures that are likely to be used by fish), if beavers undertake extensive caching of felled material for use during periods of ice cover.

8. CONCLUSIONS & RECOMMENDATIONS

The report and supporting GIS provide a detailed baseline statement of the macrophytic vegetation of lochs at Knapdale in 2008, prior to a trial reintroduction of beavers in 2009. The principal conclusions are presented below

- At the current time, the primary lochs support aquatic vegetation of high quality that is characteristic of oligotrophic or mesotrophic waters. *Nymphaea alba* and *Potamogeton natans* are the most abundant and widely distributed species. Notable features are the diversity of pondweed species and the presence of sizeable populations of several nationally or locally scarce species, including *Cladium mariscus*, *Nuphar pumila*, *Potamogeton praelongus* and *P.* x *zizii*, each occurring at several sites.
- Most of the secondary lochs are affected by significant fluctuations in water level and the two largest, Daill Loch and Loch an Add, are virtually devoid of aquatic vegetation. One smaller reservoir, Lochan Duin, was of an equivalent status in terms of its aquatic vegetation, to several of the primary lochs.
- The limitations of making species level comparisons between lake macrophyte surveys undertaken in different years are discussed. Taking these into account, it appears that the only significant change in the vegetation of the Knapdale lochs during the last two decades has been the invasion of Lochs Barnluasgan and Coille-Bharr by *Elodea canadensis*. Currently, this species is absent from all other primary and secondary lochs and the potential for further spread appears limited.
- Significant impacts of beavers on aquatic vegetation in the Knapdale lochs are unlikely, although herbivory represents an additional disturbance, which, in naturally less productive lakes, could lead to contraction of the cover of preferred species in certain areas.

A number of recommendations have resulted from this work.:

- Baseline and future surveys should be seen as part of a tiered approach to the monitoring of aquatic vegetation. A single, full survey, including full polygon mapping should be undertaken, preferably by the same personnel, at the close of the trial.
- Annual surveys should be undertaken at the fixed transects established within each loch, using non-destructive sampling methods, in order to provide cost-effective surveys and to reduce the effects of inter-surveyor variability and incomplete detection.
- Aerial photography may provide a cost-effective option for rapid, high resolution surveys, at a whole-lake scale, of the extent of aquatic vegetation. However, adequate ground-truthing would be required. The use of aerial photography should be reconsidered for application in September 2010, by which time any significant effects of herbivory by beavers ought to be evident. However, the overall value of aerial surveys may be constrained by the extent of riparian woodland around all lochs, which will obscure some open water areas due to overhang or shadow.
- Targeted surveys should be undertaken in September each year at locations in which beavers are active, in order to quantify their effects adequately. This is because fixed transect points have a low probability of capturing the very small and highly dispersed sites in which beavers tend to feed. Such surveys would need to focus on feeding stations, identified by plant remains, and to compare composition and abundance at these points, to other sites located at increasing distance from each station.

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10. PLATES

*Figure **2**. Loch Barnluasgan, looking north eastwards from south western apex over beds of Phragmites australis, Schoenoplectus lacustris and Nymphaea alba.*

*Figure **3**. View south westwards over large sheltered bay in south west corner of Loch Coille-Bharr. Note extensive Equisetum fluviatile in foreground, fringing Phragmites to rear and large areas of floating-leaved vegetation in middle foreground.*

*Figure **4**. Creagmhor Loch. View from south western apex looking northwards showing extent of fringing mire vegetation and small trees. A stand of Cladium mariscus is visible in the centre of the picture.*

Figure 5. Dubh Loch 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 **6**. Loch Fidhle looking north eastwards from south westerly apex over extensive mixed emergent and floating-leaved vegetation.*

Figure 7. Loch Linne looking north eastwards from near landing stage, over beds of Nymphaea alba and Schoenoplectus lacustris.

Figure 8. Loch Losgunn, view north-east from south westerly apex, looking over sparse Nymphaea alba and Potamogeton natans beds. Nymphaea to right of picture is undergoing terrestrialisation and replacement by Carex rostrata.

*Figure 9. Un-named Loch (N), view north-east from south westerly apex, looking over mixed Nymphaea alba and Potamogeton natans beds with terrestrialising N***.*** *alba in middle foreground.*

Figure 10. Daill Loch, eastern basin, showing extent and proximity of conifer afforestation.

Figure 11. Loch an Add. North-east shore showing typical substrate and extent of reduced water level.

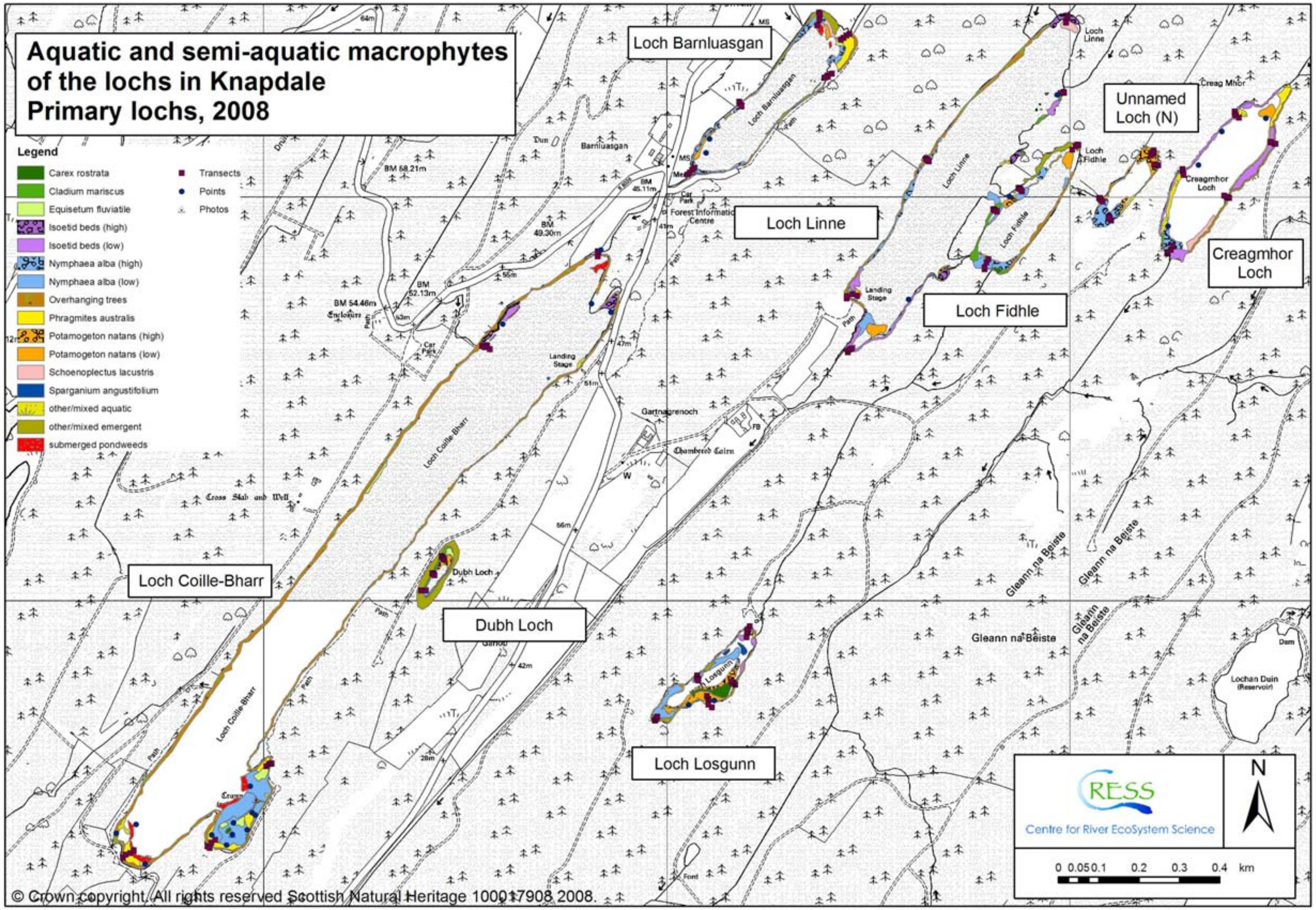
Figure 12. Lochan Duin, southern end showing beds of Equisetum fluviatile, intermixed with Nuphar pumila.

Figure 13. Draw-down zone at north end of Loch na Bric. Note steep rock exposures along north-east shore in background.

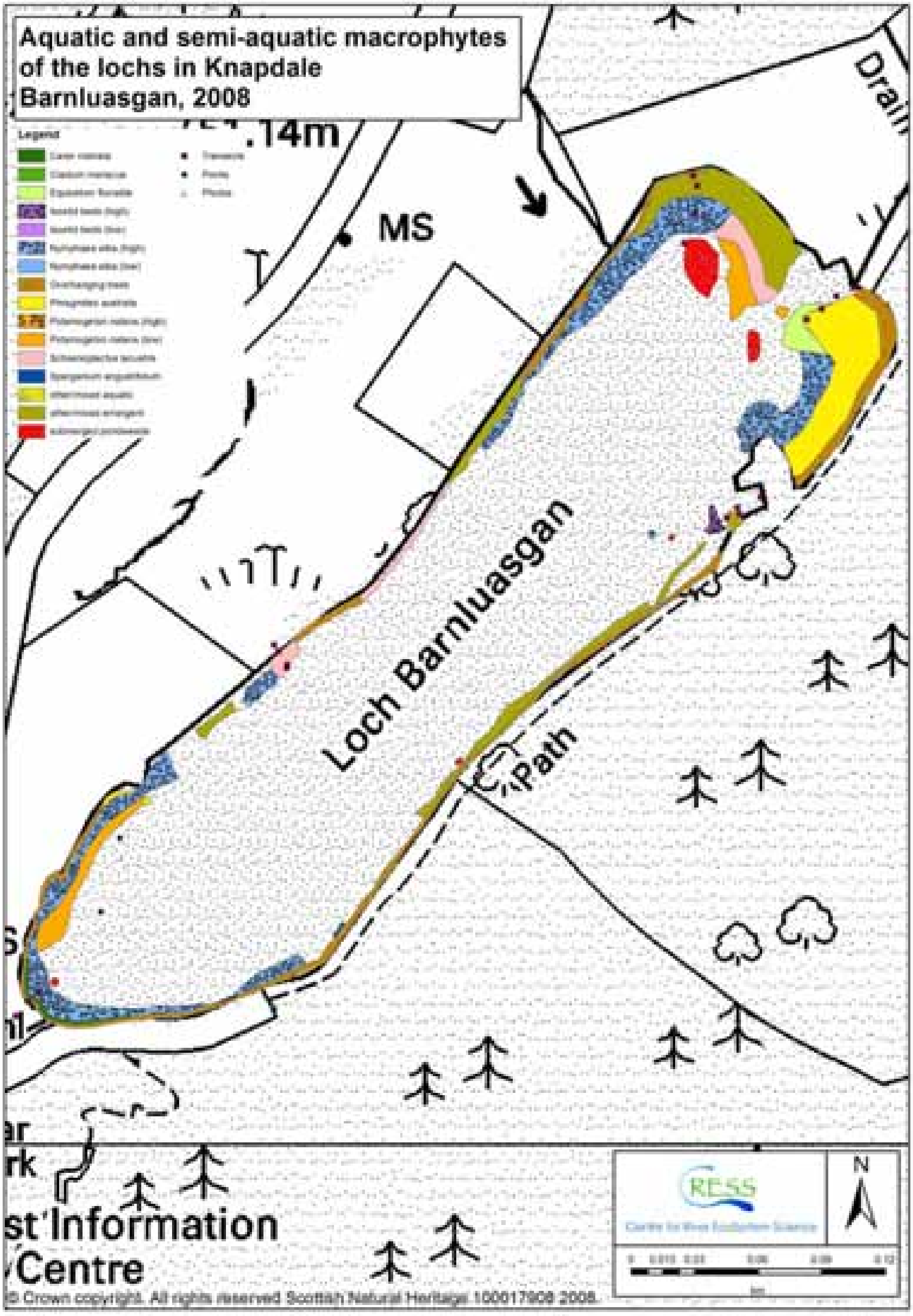
APPENDIX 1

Vegetation maps for primary lochs

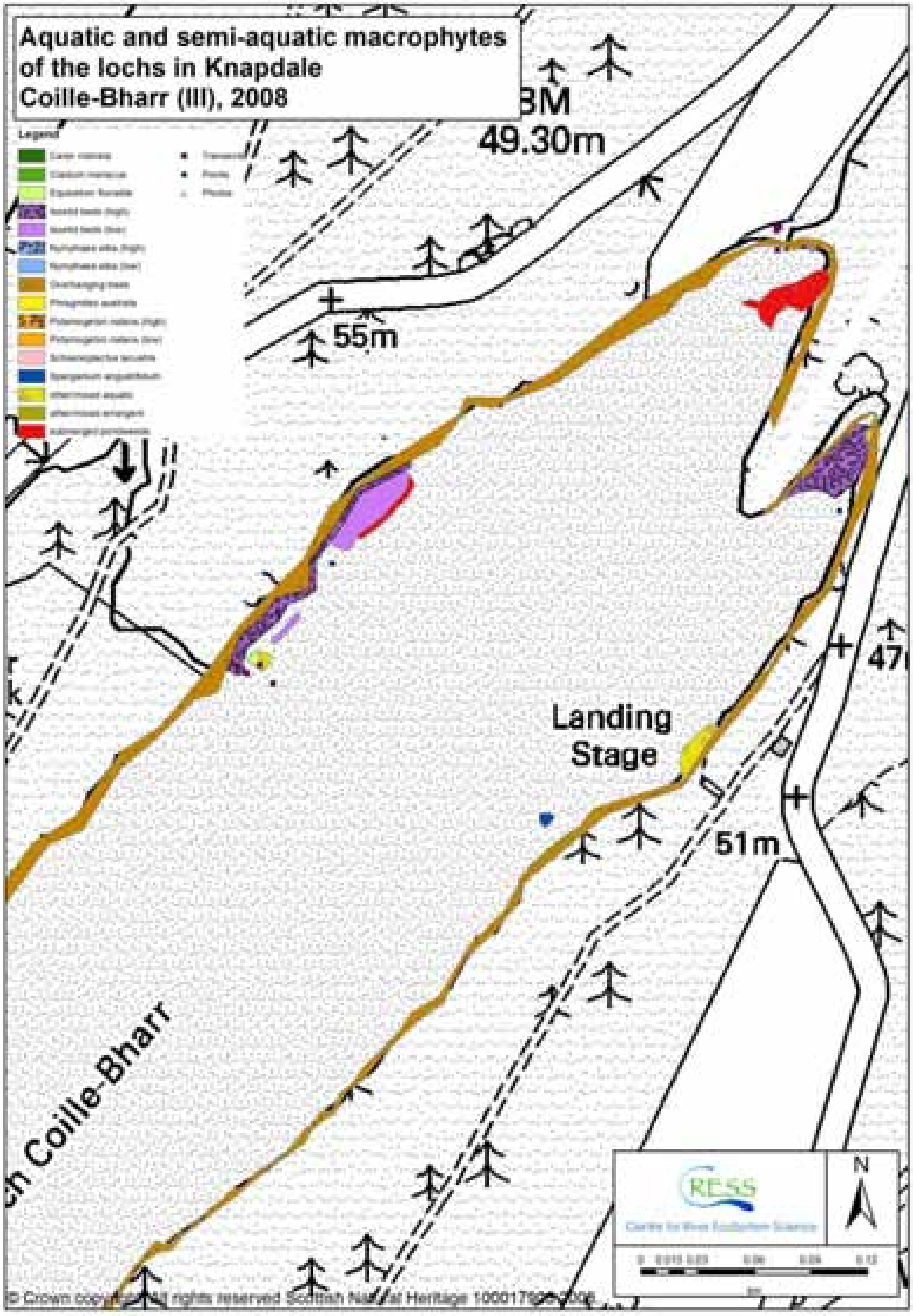
Map 1. Overview of polygon distribution in all primary lochs



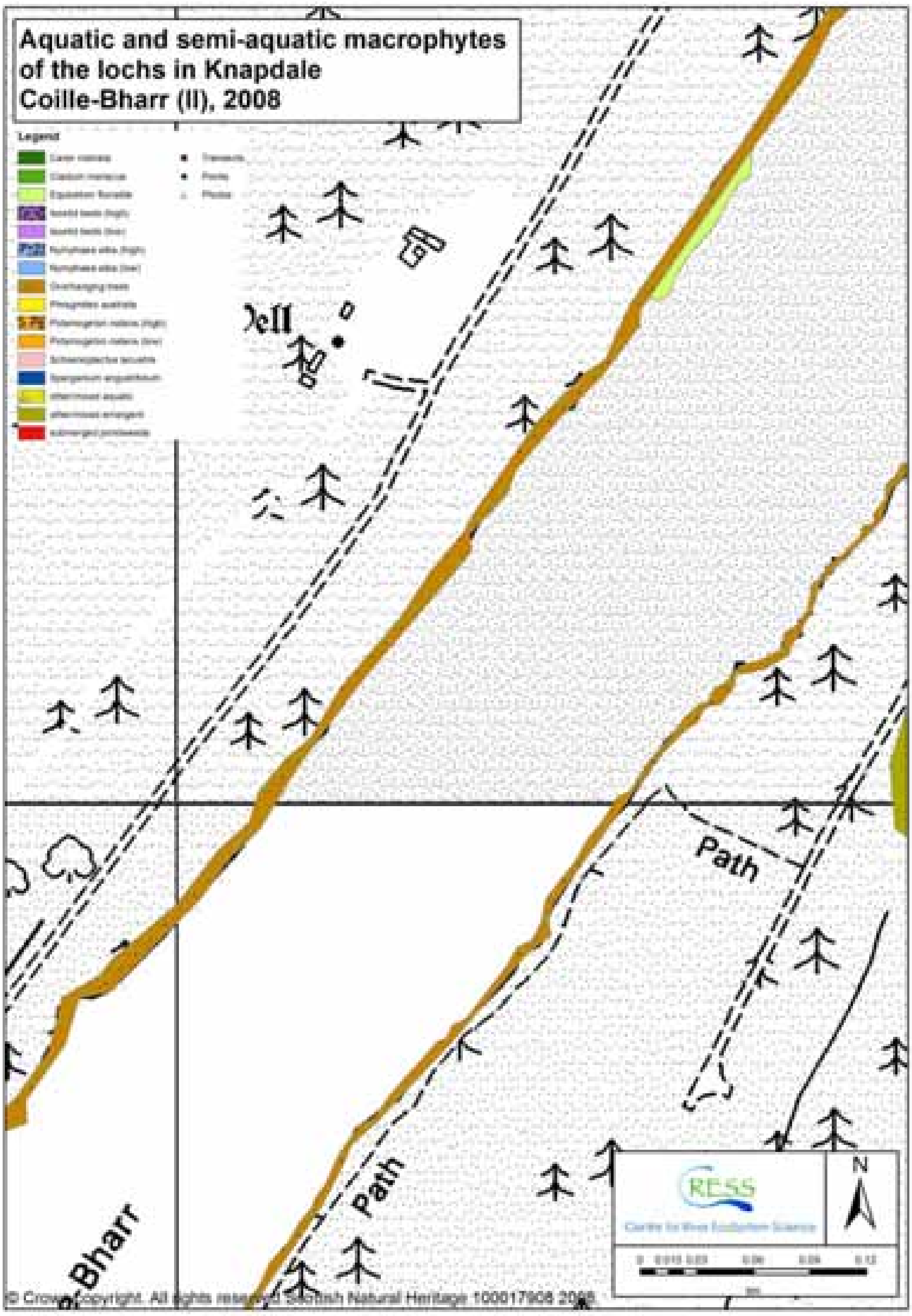
Map 2. Polygon, point and transect distribution in Loch Barnluasgan



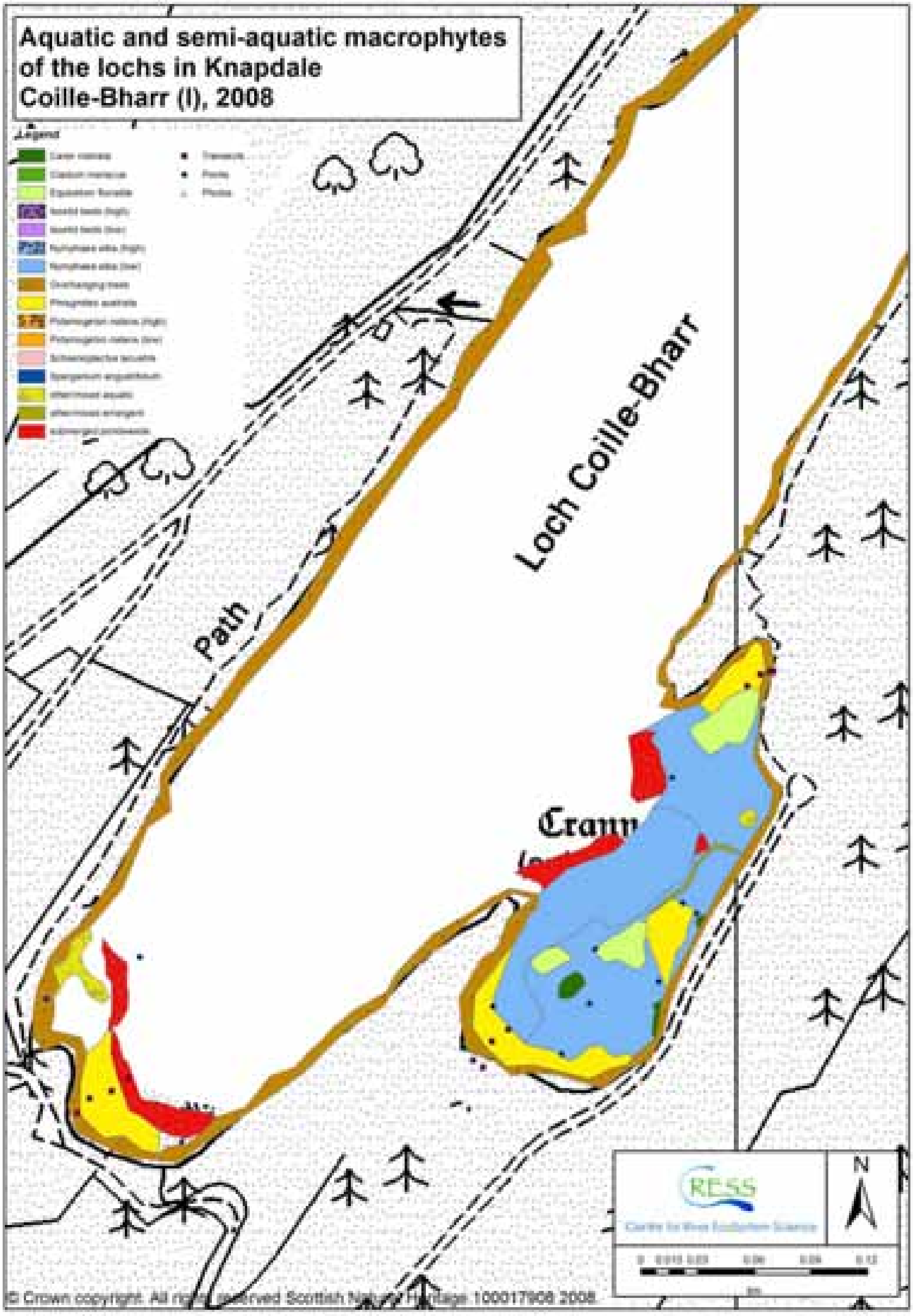
Map 3. Polygon, point and transect distribution in Loch Coille-Bharr (north)



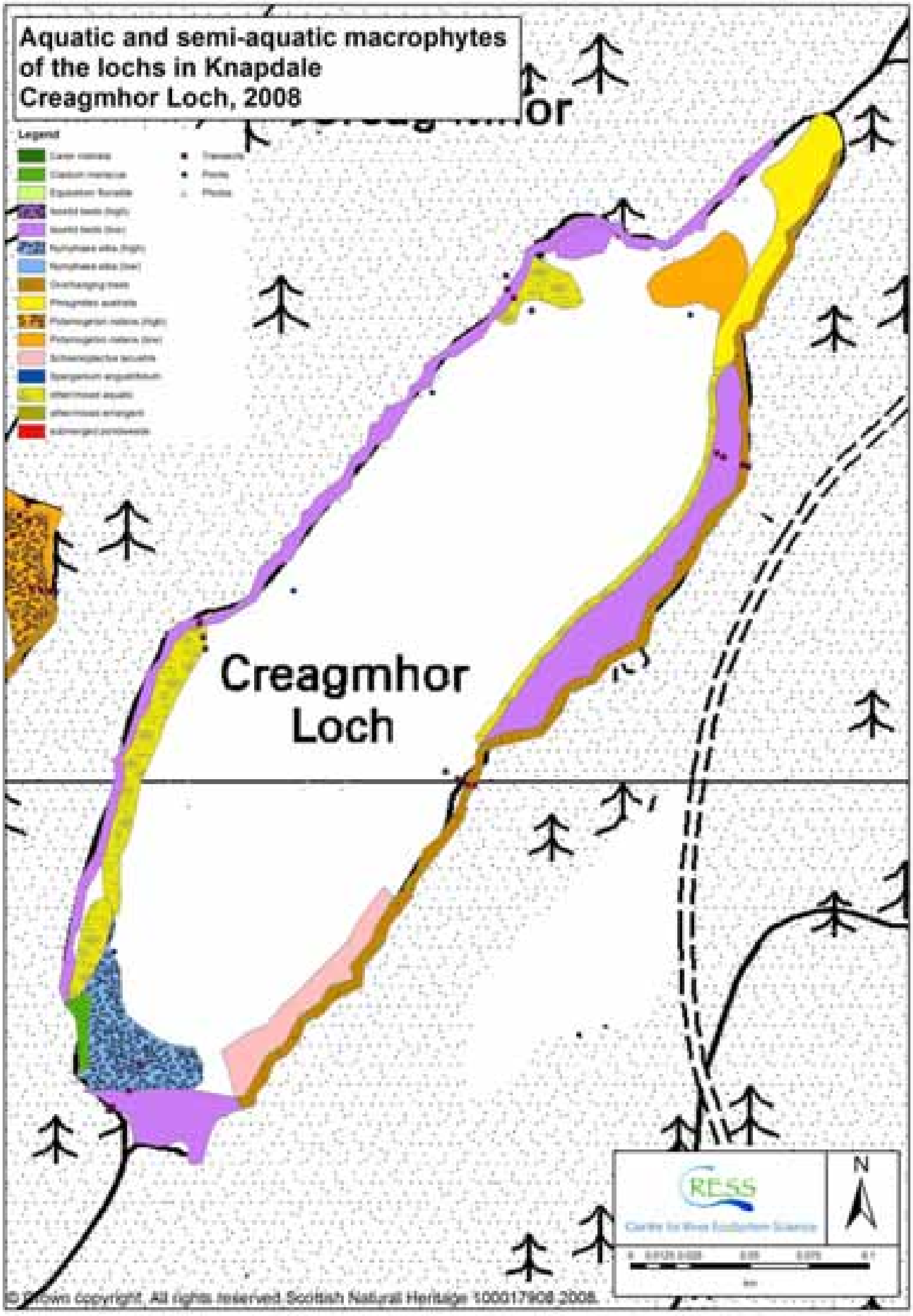
Map 4. Polygon, point and transect distribution in Loch Coille-Bharr (mid)



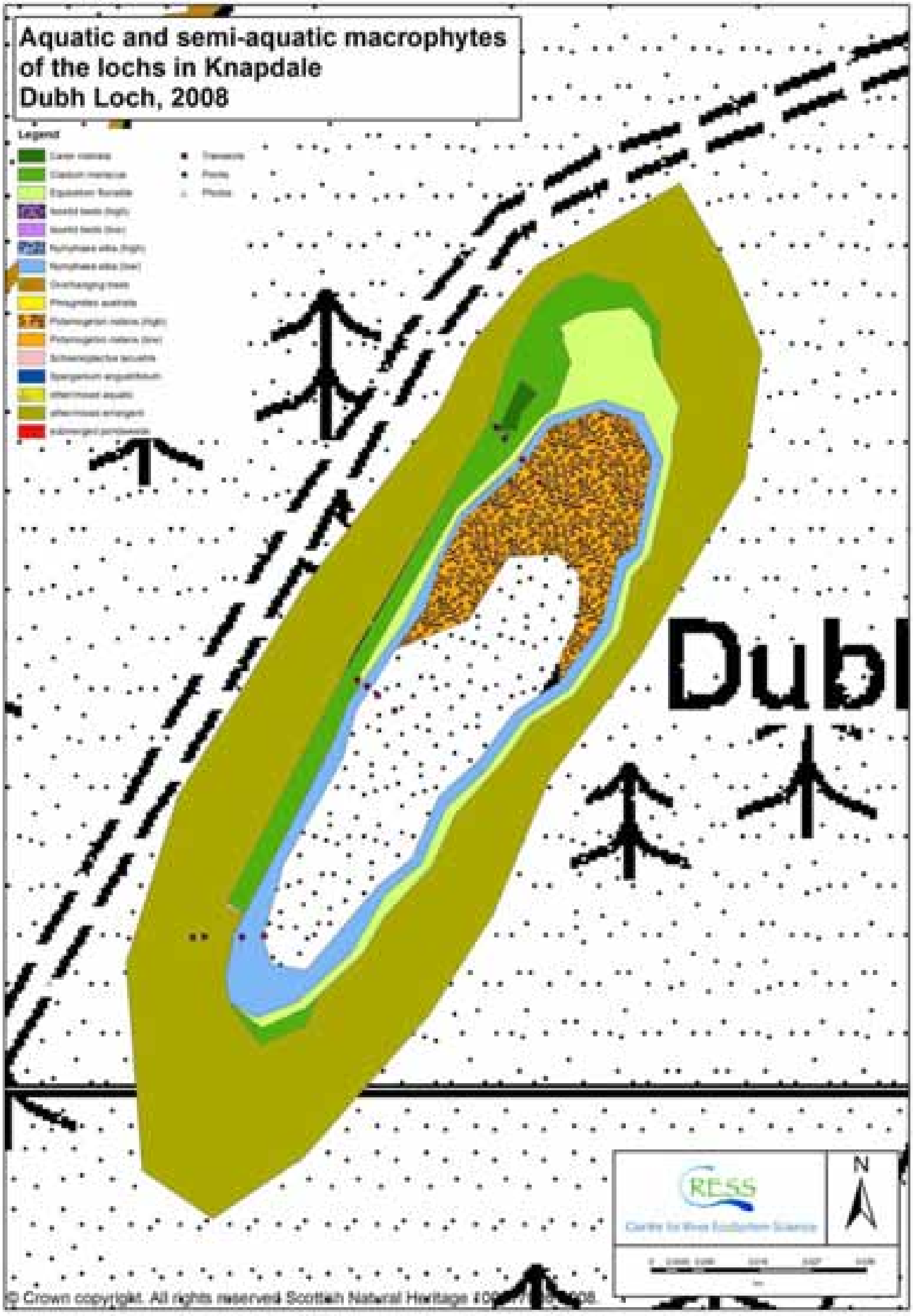
Map 5. Polygon, point and transect distribution in Loch Coille-Bharr (south)



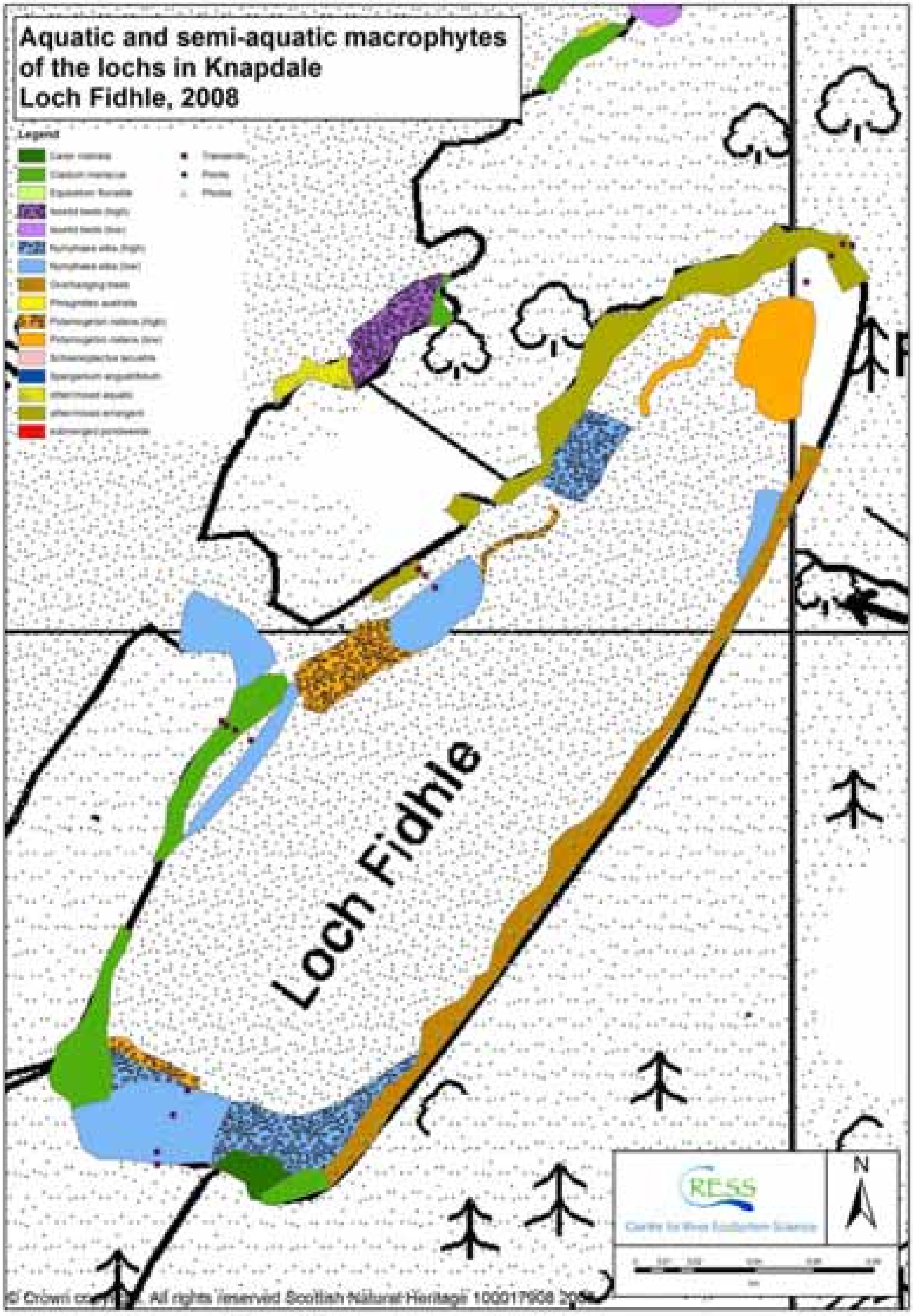
Map 6. Polygon, point and transect distribution in Creagmhor Loch



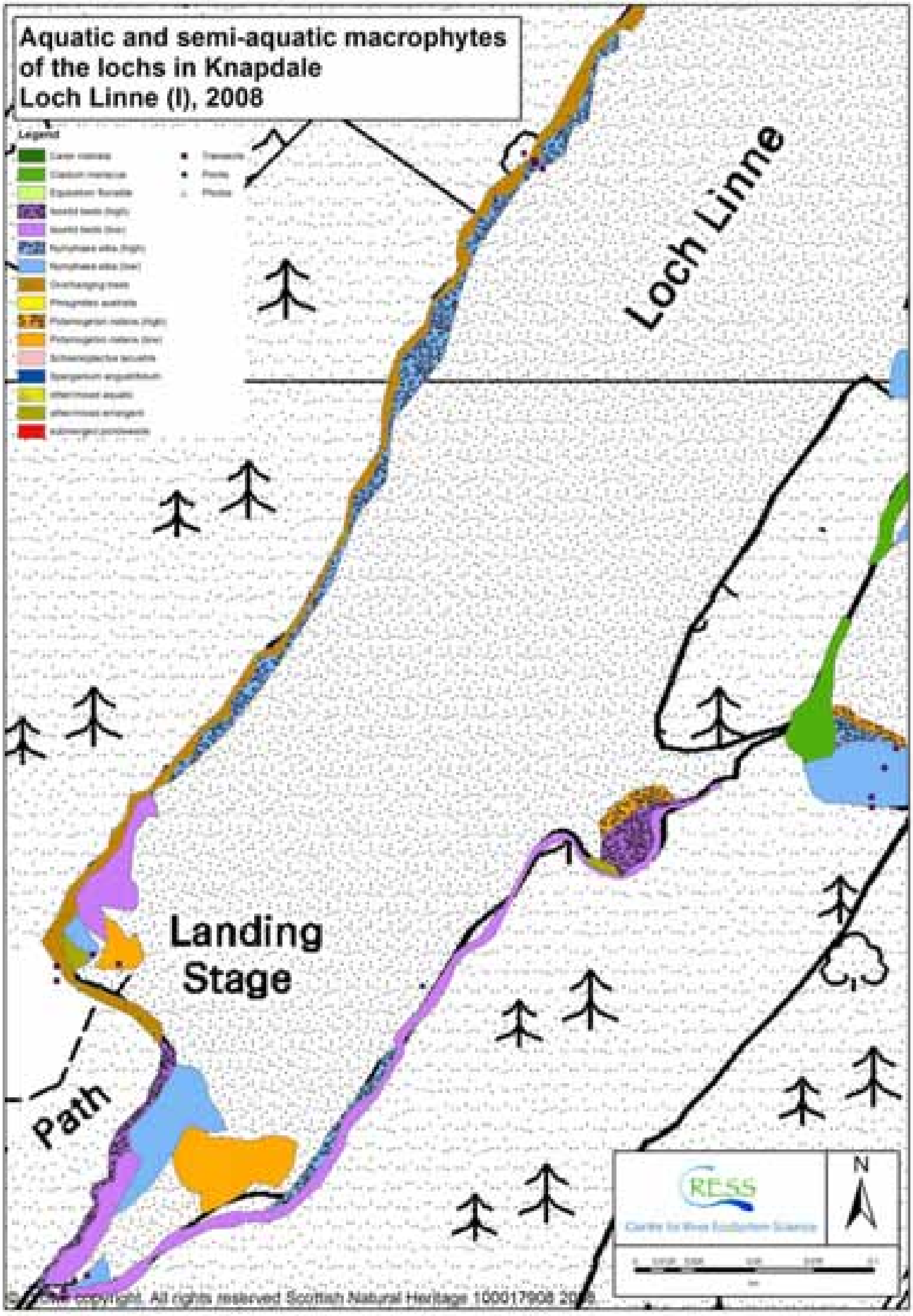
Map 7. Polygon, point and transect distribution in Dubh Loch



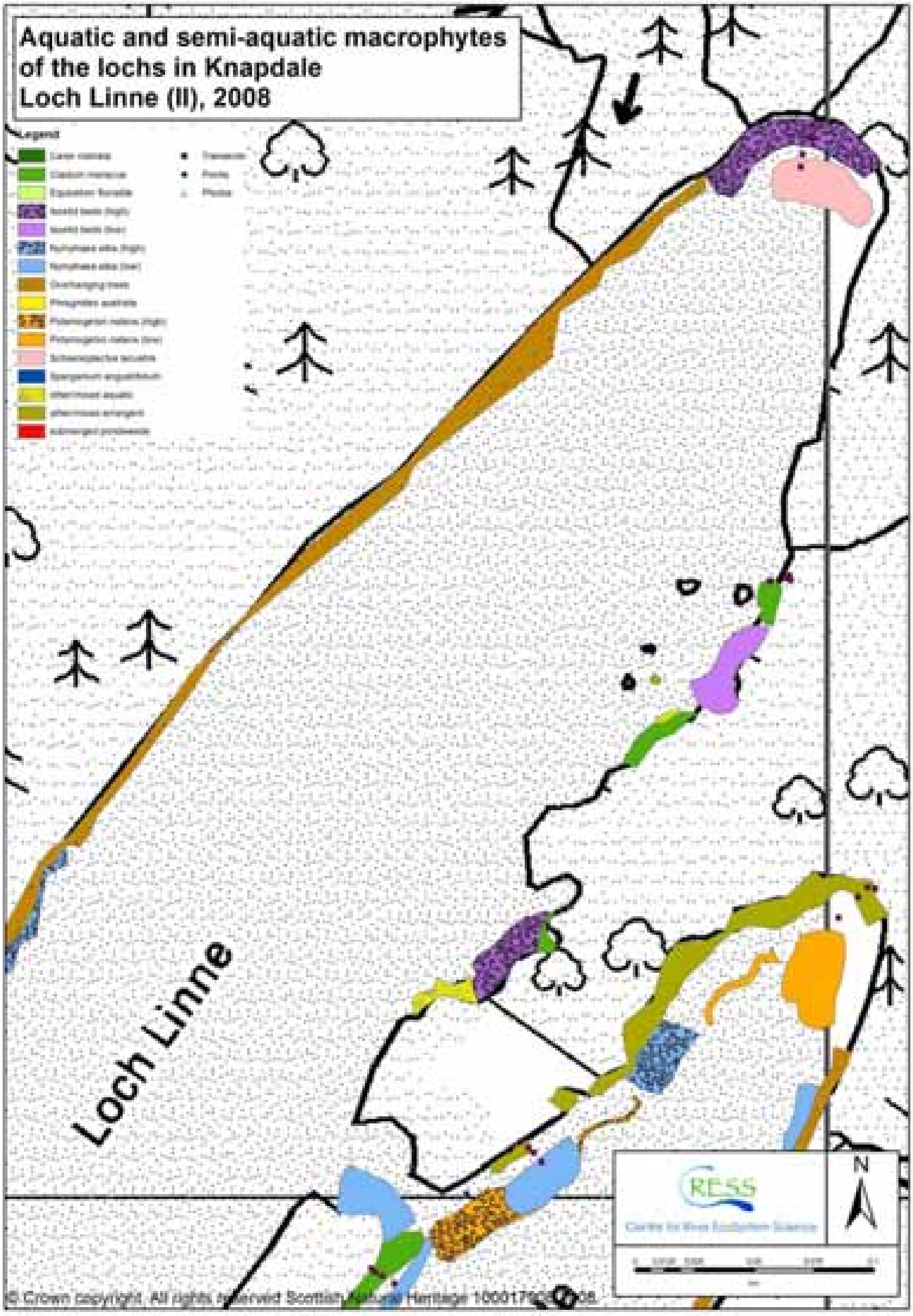
Map 8. Polygon, point and transect distribution in Loch Fidhle



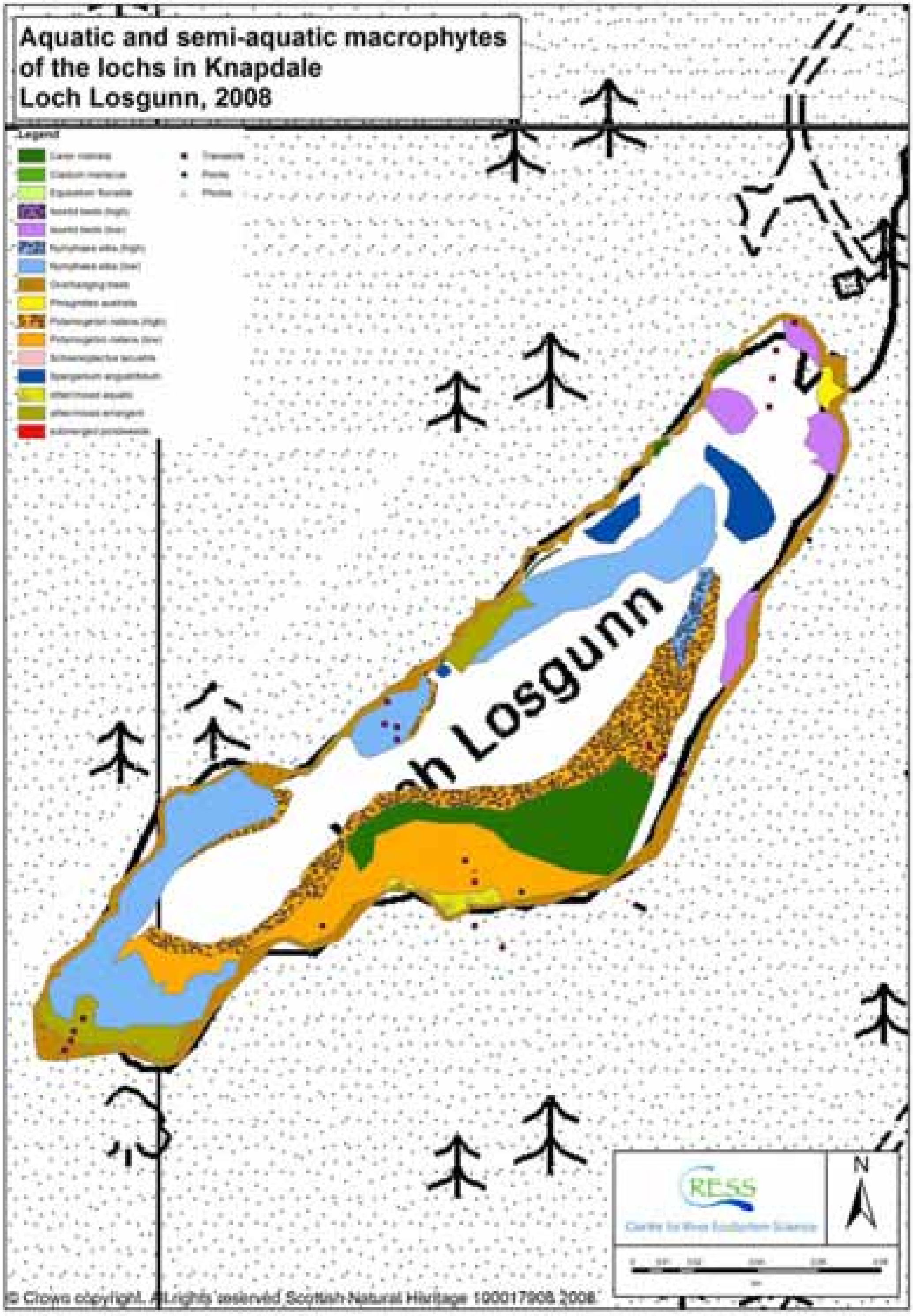
Map 9. Polygon, pfoint and transect distribution in Loch Linne (south)



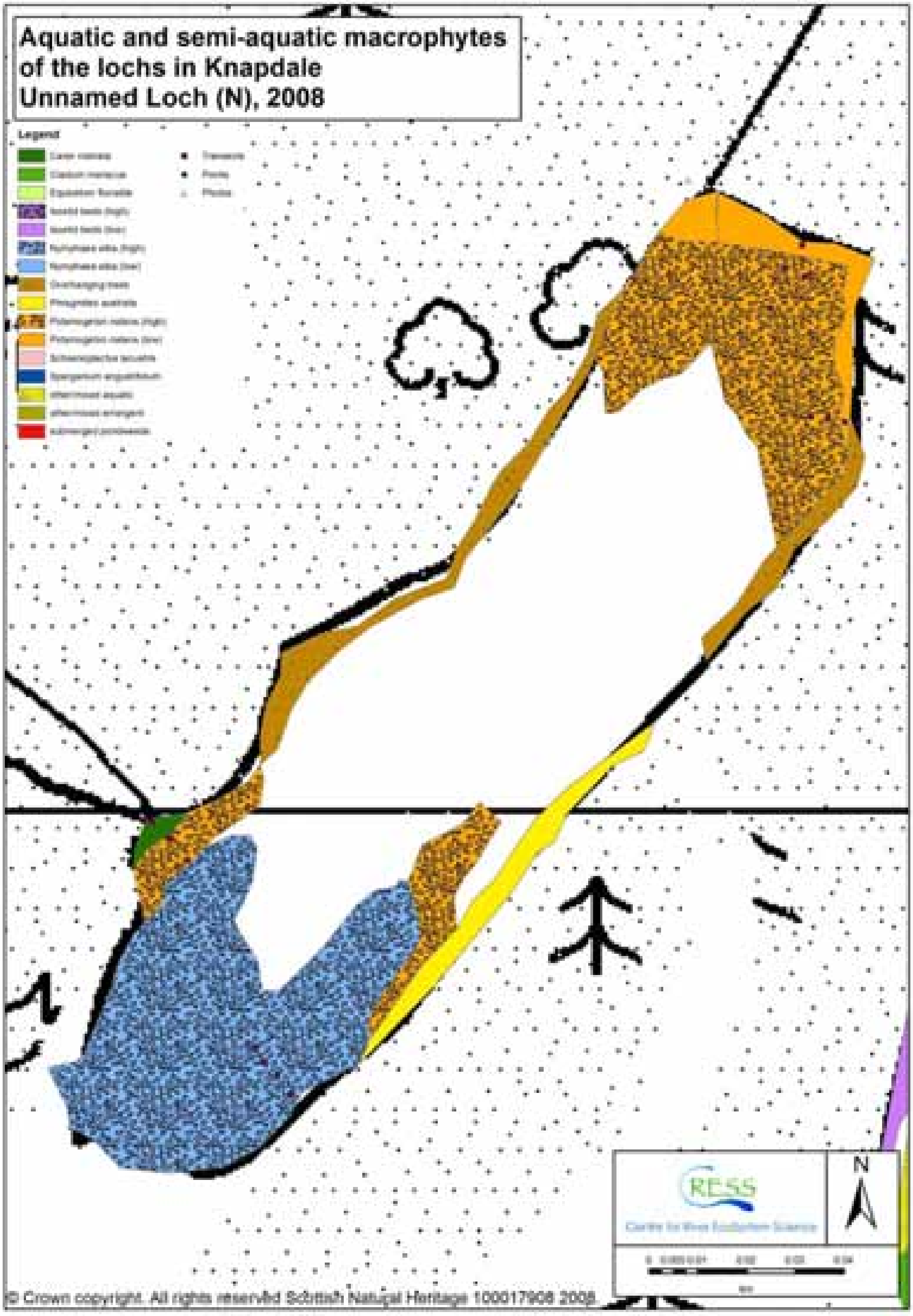
Map 10. Polygon, point and transect distribution in Loch Linne (north)



Map 11. Polygon, point and transect distribution in Loch Losgunn



Map 12. Polygon, point and transect distribution in Un-named Loch (North)



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

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